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LOOKING AHEAD:
LONG-TERM ECOLOGICAL RESEARCH AND MONITORING IN CANADA

Final Report of the Long-Term Ecological Research and Monitoring Panel of the Canadian Global Change Program

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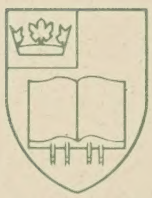

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Looking Ahead: *Long-Term Ecological Research and Monitoring in Canada*

Final Report of the Long-Term Ecological Research and Monitoring Panel of the Canadian Global Change Program

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Preface

In early 1992, the Canadian Global Change Program (CGCP) of the Royal Society of Canada established a Panel on Long-Term Ecological Research and Monitoring. The terms of reference of the Panel were:

1) To review the current state of long-term ecological research and monitoring in Canada and internationally.

2) To attempt to ensure compatibility, to the greatest extent possible, in terms of data acquisition, protocols and analysis among the various projects, either existent or planned, in order to facilitate comparison and integration of results both within Canada and internationally.

3) To identify any apparent gaps in the Canadian or international efforts that should be filled by Canadian researchers and initiate the preparation of appropriate research proposals to address these.

The Panel met first in August 1992, when it decided that there was a need for a short monograph: *circumscribing* the subject; *providing* a conceptual framework; *describing* current activities in this field in Canada, and, for comparison, in selected other countries; and *recommending* ways in which ecological research and monitoring could better meet long-term Canadian requirements. The Panel has given priority to the International Geosphere-Biosphere Programme (IGBP) but there are many other reasons for undertaking ecological research and monitoring in Canada. These have not been overlooked.

In the course of its deliberations, the Panel uncovered a wide range of ecological research and monitoring activities across Canada; research of very high quality and involving significant numbers of internationally recognized specialists. But the total effort is fragmented into disciplines, environmental media (i.e. air, water, soil, biota, etc.) and specific issues. The need to maintain long-term ecological data banks has only recently been widely appreciated, and the institutional and financial support for such an effort is not yet secure. These points are taken up in this report which was written to provide funding agencies, research managers, policy makers, ecologists, graduate students and interested members of the general public with an overview of the benefits and needs of a successful Canadian LTERM program. The Panel hopes particularly to influence the young scientists who will have to live with the consequences of current LTERM planning.

The words appearing in the title of this report have the following meanings:

- **Long-term** implies that an activity or program is intended to continue indefinitely, e.g. a weather observing network, even though funding is subject to periodic review;

- **Ecological** refers to a community of organisms (including humans) interacting with one another, plus the environment in which they live and with which they interact. Ecosystems are often embedded within other ecosystems of larger scale;

- **Research** is the endeavour to discover new knowledge or to reinterpret existing data, by critical study;

- **Monitoring** is a system of continued observation, measurement and evaluation for defined purposes. Monitoring and research are generally iterative processes.

Hereafter, the acronym LTERM will be used for the expression *long-term ecological research and monitoring.*

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The Panel especially acknowledges the contribution of Ray Tomalty in the preparation of this "short version" of this report. Richard Fleming (Forest Pest Management Service, Sault Ste-Marie) also provided valuable comments on a semi-final version of this report.

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Table of Contents

PREFACE i

ACKNOWLEDGEMENTS ii

MEMBERS OF THE LTERM PANEL iii

TABLE OF CONTENTS v

EXECUTIVE SUMMARY vii
List of Recommendations viii

CHAPTER 1: THE NEED FOR A CANADIAN LONG-TERM ECOLOGICAL RESEARCH AND MONITORING PROGRAM 1
1.1 The LTERM Approach 1
1.2 The Need for Dedicated LTERM Sites 2
1.3 Locating LTERM Sites 2

CHAPTER 2: THE ECOSYSTEM APPROACH TO LTERM 3
2.1 Ecosystem Change and Integrity 3
2.2 Monitoring Ecosystem Change 6
2.2.1 Terrestrial Ecotones 6
2.2.2 Biodiversity 6
2.3 Some Tools of the Trade 7
2.3.1 Remote Sensing 7
2.3.2 Paleoecology 8
2.4 Conclusions 8

CHAPTER 3: GLOBAL CHANGE AND THE CANADIAN ENVIRONMENT: SCENARIOS FOR THE 21ST CENTURY 9
3.1 Socioeconomic Sources of Ecological Change 9
3.2 Biophysical Sources of Ecosystem Change 12
3.3 Conclusions 13

CHAPTER 4: EXISTING LTERM-RELEVANT PROGRAMS 14
4.1 LTERM Activities in Canada 14
4.1.1 Modified Ecosystems 14
4.1.2 Unmodified Ecosystems 15
4.1.3 Federal Initiatives on LTERM 17
4.2 Canada's Role as a Participant in International Programs 18
4.2.1 International Geosphere-Biosphere Programme (IGBP) 18
4.2.2 DIVERSITAS 20
4.2.3 Sustainability of the Biosphere 20
4.2.4 Critical Environmental Zones 20
4.2.5 The UNESCO MAB Biosphere Reserve Program 20
4.2.6 The International Tundra Experiment 22
4.3 Some LTERM-Relevant Studies in Other Countries 22
4.3.1 The U.S. Long-Term Ecological Research Network 22
4.3.2 Environmental Monitoring and Assessment Program (EMAP) 22
4.3.3 LTERM-Type Studies in Fenno-Scandinavia 24
4.3.4 Serengeti: An African Example 25
4.4 Conclusion 25

CHAPTER 5: A PROPOSED CANADIAN LTERM PROGRAM 26
5.1 Principles of a Canadian LTERM Program 26
5.1.1. An Ecosystem Approach 26
5.1.2 Space and Time Scales 26
5.1.3 Stressed and Already Degraded Ecosystems 27
5.1.4 Program Continuity 27
5.1.5 A Variety of Perspectives 27
5.2 Objectives of a Canadian LTERM Program 28
5.3 Meeting the Objectives: Some Practical Considerations 29
5.3.1 LTERM Sites and Stations 29
5.3.2 Key Research Considerations 30
5.3.3 Collecting and Managing Data 31
5.4 Network Analysis 31
5.5 Some Questions To Be Asked When Establishing an LTERM Facility 33
5.6 Relation Between This Panel's Recommendations and Environment Canada's Program on LTERM 33

CHAPTER 6: IMPLEMENTATION 34

BIBLIOGRAPHY 35
Cited References 35
Further Reading 38

APPENDIX A: GLOSSARY 39

APPENDIX B: LIST OF KEY CANADIAN MONITORING PROGRAMS 41

APPENDIX C: ACRONYMS 43

Executive Summary

Sustainability of the Canadian renewable resource base is fundamental to the economic well-being of the country. The collapse of the East Coast fisheries is an example of what can happen to a profitable resource-based industry, and if global environmental change scenarios for the 21st century prove to be well founded, more economic shocks are in store for Canadians.

The Panel recommends that a national long-term ecological research and monitoring program (LTERM) be established in Canada. Such a program, would result in:

- increased understanding of ecosystem functioning, thus contributing to better management of natural resources;
- improved early warning of undesirable trends in ecosystem behaviour;
- early demonstration of the effectiveness of strategies for long-term management of natural resources.

The cost of a national LTERM program, while not insignificant, represents only a small percentage of the economic losses that would occur if Canada's resource base were to become seriously impaired. In a risk-management context, a fully operational Canadian LTERM is crucial.

Some of the priority elements in a Canadian LTERM program are as follows:

Program Continuity

A main recommendation is that the program be long-term (decades to a century). This is because ecological systems often have cycles of many decades. To overcome institutional difficulties with respect to continuity of financial support and security of facilities, it is recommended that long-term institutional and financial support be provided by the Government of Canada, in collaboration with the provinces and the community of Canadian ecologists. Because of the importance of Canada's renewable resource base, it might in fact be desirable to enshrine a Canadian LTERM program in an act of Parliament. A number of groups within Environment Canada are already moving in this direction, and their initiatives should be supported.

Collaboration With Relevant Continental and Global Programs

Canada contains a significant fraction of the earth's land and water surface. Thus Canadian participation in international terrestrial ecological programs, particularly the International Council of Scientific Unions' International Giosphere-Biosphere Program (IGBP)/Global Change and Terrestrial Ecosystems (GCTE) and the United States' Long Term Ecological Research (LTER) and Environmental Monitoring and Assessment Program (EMAP), should be given priority. These programs will be the better with Canadian participation, and they will lead to improved understanding of ecosystem functioning in general, and of the behaviour of Canadian ecological systems in particular.

The Need for a Network of Dedicated LTERM Stations

A network of LTERM stations should be established across Canada, building on existing facilities and programs. Because of the wide variety of ecological conditions across Canada, LTERM sites need to be selected carefully if networking is to be effective. Sites need to show sensitivity to global influences, high specificity to stress-producing factors, and should be representative of larger ecological areas. Each terrestrial LTERM site should contain within its bounds, a small calibrated catchment, providing basic information on hydrological and biogeochemical cycling.

LTERM sites should be established not only in wilderness areas such as national parks, but also in managed and degraded areas. LTERM studies of marine ecosystems should be carried out at least at the level of estuarine, open ocean, coastal and ice-dominated systems. Included also should be terrestrial and marine sites where suburban or industrial development is expected in coming decades, as well as areas already severely degraded.

Spacial Scales from Local to Global

Research programs span spacial scales from local to global. Special issues exist with respect to local patchiness, habitat destruction, and in the case of terrestrial systems, fragmentation and corridor degradation at the landscape level, and major climatic and other stresses at the continental and global scales. There are many interactions between scales, which can only be revealed through networks of stations, remote sensing, and field transects extending hundreds or thousands of kilometres.

Time Scales from Seasons to Centuries

It is recommended that the Canadian LTERM program maintain a time perspective of 50 years or longer. Because unprecedented change is possible in the 21st century, the Panel recommends that the Canadian LTERM give priority to the development of early warning indicators of change.

Key Research Topics

- to study the relationships amongst biodiversity, ecosystem functioning, integrity and sustainability;

- to provide early warning of long-term changes in ecosystems;
- to study ecotones, critical environmental zones and areas undergoing cumulative effects;
- to study habitat destruction and renewal, the effects of corridors and fragmentation, and ecosystem responses to perturbation;
- to undertake long-term controlled experiments, with respect to harvesting methods, manipulation of succession, etc.

National Data Management

Because of conflicting standards of information management and irregularities in the way data are stored and accessed, it is recommended that Canada establish a national data management strategy. This should be compatible with relevant international efforts. About 10-15% of the LTERM budget should be spent on quality control, data storage and documentation.

Socioeconomic Components of LTERM Programs

To understand the causes of long-term ecological change, socioeconomic factors must be considered. For example, changes in land cover are caused by changes in land and water use (including crops grown, irrigation and fertilizers used, etc.) and changes in the driving socioeconomic forces that result in changes in land-use (e.g. changes in population density, number of timber concessions, market prices, etc.). To provide early warning of a possible loss in ecosystem integrity due to the pressure of land-use changes, the relevant socioeconomic factors must be included in LTERM models and monitoring programs.

An Integrated Approach to Ecosystem Monitoring

Each ecosystem should be studied from as many different perspectives as possible, including hydrologic cycling, biogeochemical cycling of carbon and other substances through the ecosystem, food webs, overall energetics, geomorphology and soils, population dynamics. These perspectives should be applied in an integrated fashion rather than applied separately as is frequently done. This would help in deciding monitoring priorities.

Implementation

The Panel recommends that Environment Canada be asked to be the lead agency for an LTERM Program in Canada. An LTERM standing Committee of the CGCP, composed of a non-governmental group of experts should be established to play an advisory role.

List of Recommendations

The following recommendations are extracted directly from the report. The first number in parenthesis indicates the chapter of origin, the second indicates the order of appearance in each chapter.

Recommendation (1.1): Noting that the 21st century may be a period of unprecedented socioeconomic and environmental changes, it is recommended that a national Canadian LTERM program should be given the highest priority. This program would include a network of LTERM sites which would be established across Canada, building on existing facilities and programs.

Recommendation (1.2): Some of the sites should be in wilderness areas dedicated to LTERM studies. Other sites should be in areas containing managed ecosystems and in areas containing highly stressed or already degraded ecosystems. Special attention should be given to the preparation of guidelines for operating LTERM facilities in such areas.

Recommendation (2.1): Research into non-equilibrium thermodynamics ought to be one of the centrepiece themes of a Canadian LTERM.

Recommendation (2.2): In the context of biodiversity, habitat destruction and fragmentation should be monitored on a long-term basis.

Recommendation (2.3): The Canadian LTERM program should seek close working relations with the paleoecology and remote sensing communities in Canada. In both cases, the human resources and technical support already available will be invaluable.

Recommendation (2.4): Ecosystems need to be studied on many spatial and temporal scales (from local to continental, and from decades to centuries). Of particular importance is the patchiness of ecosystems, so that the landscape scale needs to be emphasized.

Recommendation (2.5): The ecosystem approach described in this chapter allows us to recommend a number of key research topics for a Canadian LTERM program:

- Studies of the relationships amongst biodiversity, ecosystem functioning and ecosystem integrity;
- The application of non-equilibrium thermodynamics to ecosystem functioning and integrity. This ought to be a centre-piece theme of the Canadian LTERM program;
- Studies of ecotones. These provide special opportunities to examine the effects of discontinuities on ecosystem functioning. They also may be particularly useful as early indicators of global change;

- Environmental time bombs. Ecosystem functioning may sometimes be threatened over the long term by minor but accumulating stresses, and the ultimate result may be a sudden and surprising disfunctioning of the ecosystem involved.

Recommendation (3.1): The Canadian LTERM program should include a strong socioeconomic component, whose goal is to permit an integrated approach to investigations of the socioeconomic causes and consequences of long-term ecological change.

Recommendation (3.2): It is further recommended that the development of early warning indicators of long-term global change be given particular attention within this program. This will of course involve model development, field experiments and the establishment of long-term monitoring programs. Special attention should be given to UV-B monitoring in the arctic.

Recommendation (4.1): There have been many short-term studies of urban ecology, but there have been few LTERM-related programs in the urban environment. Therefore, it is recommended that urban ecosystems research be given attention comparable to that given to agricultural, forest and other less modified ecosystems.

Recommendation (4.2): Considering the importance of sustainable agriculture and forestry to Canadians and Canadian export markets, and considering the importance of soils and soil processes to ecosystems, it is recommended that the Canadian Soil Quality Benchmark Sites program be incorporated into a Canadian LTERM program.

Recommendation (4.3): It is recommended that forestry departments, forest companies and schools collaborate to institute a national system of tree sample and permanent plot data repositories. To support this initiative, research should be undertaken on criteria and indicators.

Recommendation (4.4): It is imperative to establish and support a long-term monitoring and research program that would follow structural and behavioural changes in several selected tundra sites. Information obtained will establish a reference base, against which all future changes will be compared. It will also assist in formulation of northern social, demographic and economic policies, and in management of renewable resources.

Recommendation (4.5): Marine areas should be included in a Canadian LTERM network. This shoud be done by building on existing marine ecosystem monitoring programs and by developing them to reflect the hierarchies within Canada's various marine ecozones.

Recommendation (4.6): There has been a wealth of ecosystem information collected for national park management, but the localized nature of the studies has resulted in a lack of standardization in methodology and data structures, both between parks and between study repeats. It is therefore recommended that Parks Canada institute a process of ecological data standardization and dissemination, in the context of LTERM.

Recommendation (4.7): National Parks are established in law to protect representative examples of Canada's natural diversity. This makes them ideal sites for LTERM, especially in light of the prospect of being able to repeat studies decades or centuries hence. However, landscape modifications for research purposes are not permitted in national parks. Therefore, it is recommended that portions of national parks be set aside for the purpose of establishing benchmark or reference LTERM sites where ecological manipulations could be undertaken.

Recommendation (4.8): Canada contains a significant fraction of the Earth's land and water surface. Thus Canadian participation in international terrestrial and marine ecological programs, particularly IGBP/GCTE, should be given high priority.

Recommendation (4.9): It is recommended that the Canadian LTERM program maintain both a continental and a hemispheric perspective. Close liaison should be developed between the Canadian LTERM and various relevant U.S. hemispheric national and state programs, and also circumpolar research studies. In the case of marine LTERM programs, the spatial scales involved must be sufficiently large to correspond to those that include the life cycles of the species involved.

Recommendation (4.10): It is recommended that the Canadian LTERM program maintain a long-term (50 years or longer) perspective. Accepting the precautionary principle and assuming that ecological changes will indeed occur, considerable effort should be given to developing early warning indicators and improving our understanding of ecosystem functioning under changing conditions.

Recommendation (5.1): An ecosystem approach must be taken in the LTERM program. Ecosystems should be studied inter alia as non-linear systems with multiple states between which the system may flip.

Recommendation (5.2): Ecosystems need to be studied on a variety of temporal scales, from decades to centuries.

Recommendation (5.3): In studying ecosystems, efforts should be made to capture the effect of ecosystem patchiness on a variety of scales.

Recommendation (5.4): Each terrestrial LTERM site should preferably include within its bounds, a small calibrated catchment, providing basic information on hydrological and biogeochemical cycling.

Recommendation (5.5): Special attention needs to be given within LTERM to stressed and already degraded ecosystems, within the context of ecological integrity and sustainability.

Recommendation (5.6): A main recommendation of the Panel

is that long-term institutional and financial support be provided by the government of Canada, in collaboration with the provinces and the community of Canadian ecologists.

Recommendation (5.7): Because of the importance of Canada's renewable resource base, it would probably be desirable to ensure that an LTERM Program be supported at senior levels of the Federal and Provincial governments (i.e. Cabinet level).

Recommendation (5.8): The federal government should situate responsibility for a Canadian LTERM program in a single national agency, whether that agency be pre-existing or created for this purpose.

Recommendation (5.9): In any cost-cutting exercise, the Panel urges LTERM sponsors to accord the greatest possible protection to on-going, long-standing programs. In return, LTERM operators must accept the responsibility to maintain high levels of ecological relevance, to maintain standard methods, and to report to their peers and the public at large.

Recommendation (5.10): Ecosystems should be studied from as many perspectives as possible, including hydrological cycling, biogeochemical cycling, food webs, overall energetics, geomorphology, and soils, population dynamics, life cycle assessments, landscape patchiness and corridors, stress-response assessments and ecosystem integrity.

Recommendation (5.11): The objectives for LTERM programs should be carefully specified for each station. These objectives need not be the same across all stations in the national network.

Recommendation (5.12): Site continuity should be ensured for existing sites and shielded from undue disturbances.

Recommendation (5.13): Considerable effort should be given to improved understanding of ecosystem functioning under changed conditions, and of the potential for extrapolating findings from local to regional and even larger scales.

Recommendation (5.14): The Canadian LTERM program must establish a national data management strategy, including the development of a metadata system. This strategy should map out means for keeping up with evolving instrumentation and scientific understanding, the use of citizen monitoring programs, and the design of repositories for biological samples and data archives. About 10-15% of the LTERM budget should be spent on quality control, data storage and documentation.

Recommendation (5.15): Individual Canadian LTERM facilities should be integrated into a national network. Networking among researchers and administrators should be encouraged and facilitated through electronic mail, regular meetings of station managers and research scientists, and the above-mentioned data management strategy. [In some cases, of course, networking has been detrimental by adding bureaucracy. This tendency should be avoided.]

Recommendation (5.16): Noting that networks of LTERM stations will be required to assess a wide range of public issues and research questions, some of which cannot yet be imaged, the principle of "nested networks" should be followed, in which tiers of stations are established, each to be activated as required. These networks should be supplemented by archived remotely sensed ecological data covering the areas between stations.

Recommendation (5.17): In choosing sites, attention should be given to the kinds of questions that each site will be capable of answering, and not answering.

Recommendation (6.1): It is recommended that Environment Canada (EC) be officially recognized as the LTERM lead agency in Canada. This recognition must be backed by a commitment for long-term funding of LTERM activities in Canada and should include specific reference to the necessary reporting and advisory mechanisms that will ensure that EC plays its role of lead agency.

Recommendation (6.2): It is recommended that the Canadian Global Change Program appoint an LTERM Standing Committee that would receive reports from and provide advice to EC and other organizations involved in LTERM activities in Canada. The costs associated with the operation of this Committee would have to be covered by EC, other government departments, provincial ministries and other bodies supporting the Program.

Recommendation (6.3): It is recommended that a report on Canadian LTERM activities be prepared periodically by the proposed Standing LTERM Committee.

Chapter 1
The Need for a Canadian Long-Term Ecological Research and Monitoring Program

Interest in LTERM has grown considerably in the last two decades in all parts of the world. What brings a sense of urgency at the present time is the concern that rates of change in the 21st ccentury are likely to be unprecedented. Annual global mean surface temperature, for example, has not varied by more than a few tenths of a degree Celsius in recent centuries but climate change models suggest that there may well be a rise of 2-4°C before the end of the next century, averaged globally, with greater increases in polar regions. Because such a change would have a major impact on the World's ecosystems, the need for ecological baseline data and greater understanding of the processes involved is much more urgent than ever before.

1.1 The LTERM Approach

Why should we take the long-term approach to studying ecosystems? Several reasons can be given.

- Many ecosystems take decades, and in some cases centuries, to complete a life cycle. In this connection, it is easy to understand why forest scientists are in the forefront amongst ecologists interested in long-term research and monitoring. An example of this perspective is an experiment at the H. J. Andrews Experimental Forest in Oregon designed to continue for 200 years! Initiated in 1985, the objective is to determine the long-term decomposition and release of nutrients from logs placed at six sites on the floor of an old-growth forest (LTER, 1991).
- Biological *populations* are often subject to great year-to-year variability, and stable averages cannot be determined even over sampling periods lasting decades. Sometimes populations crash (e.g. as a result of a forest fire) or explode (e.g. insect infestations) but these may be part of natural ecological rhythms that may span decades or centuries. Studies of the decline of sugar maples in Ontario and Quebec in the 1980s brought to light the fact that this phenomenon occurred at least once before — in the early part of the century. Unfortunately, many ecological investigations are undertaken without sufficient knowledge of long-term variability in the system.
- Patchiness is one of the governing factors in the life cycle of an ecosystem. The patches are related to local moisture, soil nutrients, sunlight characteristics, seed dispersal, and the presence of competitors. Patchiness occurs on all scales from micro to landscape, and even larger. The patches are continually evolving, often changing position (as a large tree crashes to the forest floor, for example). In many cases, therefore, patch dynamics may require 50 to 100 years of observations to illuminate their characteristics.
- Much of Canada's wealth and material well-being is based on its rich endowment of natural resources, which include about 9% of the Earth's supply of freshwater, 10% of its forests, and significant reserves of oil, gas, coal and minerals. A conservative estimate of the monetary benefits of Canada's biological resources has been estimated at $70 billion annually, 40% of GNP (Mosquin and Whiting, 1992). Clearly, then, ecological research should receive the highest priority. To ensure early warning of impending biological collapses, a well-organized LTERM network is essential.
- Some of Canada's ecosystems are already stressed or degraded (e.g. fisheries, acidified lakes, prairies salinized grasslands), and recovery is generally a long-term process. For such systems, the additional stresses that may occur in the 21st century due to global environmental change may trigger irreversible effects.

Box 1.1
Ecological Collapse: The Atlantic Cod Fishery

The collapse of the cod fishery in the Northwest Atlantic raises a number of questions about its causes. Data depicting the long-term trends in the marine environment are scanty and research on mechanisms affecting the recruitment and growth of marine resources is constrained by the complexity of the marine ecosystems and by the limitations of funding. An expanded long-term monitoring and research program might not have helped prevent the collapse of the fishery but could have assisted by providing insight on the productivity of fish stocks and the sustainability of the fisheries.

There is an urgent need for better synthesis and communication of information from ecosystem monitoring programs to decision-making levels. The most useful information about natural resources for a decision-maker will have several characteristics:

- the data will be collected over a sufficiently long period of time that it will be possible to distinguish short-term variations from long-term trends;

- the data will have been collected over enough different environmental conditions that researchers and decision-makers can determine the range of conditions under which the results can be meaningfully extrapolated;
- the data must measure the important variables from a number of perspectives, e.g. physical, biological, social and economic; and
- the data should be accompanied by an evaluation of its accuracy and its credibility within the scientific community

1.2 The Need for Dedicated LTERM Sites

A network of dedicated LTERM sites across Canada, building on existing facilities and programs, is essential. Such a network would:

1. Help in understanding more fully the functioning of ecosystems as a prerequisite to interacting with them in mutually beneficial ways specifically, an LTERM program could be used;
    - to determine the variability of ecosystems over periods of a decade or longer, particularly under conditions relatively free of human intervention;
    - to undertake long-term controlled experiments on the effects of human intervention in ecosystem function, such as adding lime to acidified lakes;
    - to use naturally-occurring disturbances (for example, forest fires) to develop and test modelsthat predict subsequent ecosystem changes.
2. Provide indicators of current and future trends:
    - giving early warning of long-term regional and global changes, such as the recent increase in UV-B radiation, which is associated with a depletion in stratospheric ozone;
    - providing long-term stress-response data that will help in establishing environmental standards.
3. Complement data obtained from satellites and aircraft. Increasingly, the Earth's ecosystems are being monitored remotely, and it is important to have a network of ground and water based stations to validate remotely sensed measurements, allow measurements not possible with remote sensors, and provide data during periods when a satellite is not overhead or its sensors are malfunctioning.
4. Generate benchmark information to assist in refining national inventories of ecosystem types, extent and condition.
5. Provide baseline data for environmental impact assessments to characterize the state of the environment prior to, and following, the construction of major public works.
6. Inform members of society by:
    - supplying information to the media and NGOs interested in environmental quality and trends;
    - providing information on cumulative environmental/ ecological effects, as is specified in the federal Bill C-13;
    - providing information on whether ecosystems are moving towards or away from desired states.

Recommendation (1.1): Noting that the 21st century may be a period of unprecedented socioeconomic and environmental changes, it is recommended that a national Canadian LTERM program should be given the highest priority. This program would include a network of LTERM sites which would be established across Canada, building on existing facilities and programs.

1.3 Locating LTERM Sites

Many of the LTERM facilities should be located in relatively undisturbed areas. Such regions are ideal for studying the effects of large-scale change. However, emphasis must also be given to:

- managed ecosystems, such as farmland, urban areas and managed forests, which comprise much of the land biosphere;
- degraded/stressed ecosystems, resulting from human actions such as over-grazing, pesticide/ herbicide/fertilizer over-use, suburban sprawl, and waste dumping. Such ecosystems may appear to be robust (e.g. the Great Lakes, the coastal zone, prairie wheat fields) but in fact they may have lost a considerable degree of integrity. Global change may therefore have the greatest impact in such cases.

At present, no guidelines exist on how to design an LTERM program for intentionally modified and for degraded ecosystems.

Recommendation (1.2): Some of the sites should be in wilderness areas dedicated to LTERM studies. Other sites should be in areas containing managed ecosystems and in areas containing highly stressed or already degraded ecosystems. Special attention should be given to the preparation of guidelines for operating LTERM facilities in such areas.

Chapter 2
The Ecosystem Approach to LTERM

An ecosystem is a community of organisms (often including humans), interacting with one another, and with the environment in which they live. Smaller ecosystems are embedded within larger ecosystems, up to the global ecosphere. Their precise spatial and temporal boundaries may be difficult to define, and may be merely convenient abstractions. However, this does not negate their value as a research tool or the value of the ecosystem approach in environmental management or in LTERM.

Indeed, the ecosystem approach should be a central feature of any LTERM program in Canada: it helps us ask the most appropriate questions and provides a conceptual framework for answering them in the most useful way.

The ecosystem approach allows one to suggest innovative new research agendas and formulate key questions about changes in the natural world:

- What feedbacks exist within the ecosystem, and between the ecosystem and the larger environment? Will these feedbacks compensate for structural failures in the system?
- When a change is measured in the structure of an ecosystem, how is one to decide whether its integrity is impaired or improved?
- Could a degraded ecosystem be restored to a healthier state, assuming that the functioning of the ecosystem was fully understood?
- How capable is an ecosystem of self-defence against invasions by exotic organisms?
- What *biotic* capabilities does the ecosystem have in reserve to survive and recover from occasional severe crises?
- Can evolutionary processes keep pace with the global changes expected in the 21st century?
- How can these evolutionary multi-generational processes be modeled and monitored?

Good environmental management practices emphasize the need to take an ecosystem approach. For example, river management should encompass a whole catchment area, including wetlands, farmlands and urban communities, and should embrace not only the biogeochemical but also the socioeconomic influences (Stedman and Regier, 1987; Edwards and Regier, 1990). With recent emphasis on "sustainable development," the time perspective for environmental management has lengthened into decades, and the importance of taking an ecosystem approach to LTERM increases.

Box 2.1
An Ecosystem Approach to Management of the Great Lakes (Glrab, 1978)

The essential feature of the ecosystem approach is *integration*. No single agency or organization can lay claim to the ecosystem approach because, by definition, the approach calls for *orchestration*.

2.1 Ecosystem Change and Integrity

An important development in the last 20 years has been the elaboration of the *complex systems theory*. According to this theory, a system's behaviour cannot be explained by decomposing it into pieces, whose individual behaviours can be linearly summed to give the behaviour of the whole system. Thus one cannot understand the behaviour of ecosystems from examining only the behaviour of the species within it. This has important implications for the design of an LTERM program.

Ecosystems are thermodynamically open systems, which are never in equilibrium. Thus, a non-equilibrium thermodynamic approach is needed to understand ecosystem change. When "high quality" energy is pumped into an open system, it is moved away from equilibrium. Nature, however, resists such movements. So the open system responds with the spontaneous emergence of organized behaviour that uses the high quality energy to maintain its structure, thus dissipating the ability of the high quality energy to move the system away from equilibrium. As more high quality energy is pumped into a system, more organization emerges to dissipate the energy.[1]

This self-organizing behaviour is characterized by abrupt changes that occur when a new set of interactions and activities emerges among components and the whole system. The development of self-organizing systems is characterized by periods of rapid organization followed by an interval of time during which the system maintains itself in a steady state. Organization of the system is not a smooth process but rather proceeds in spurts. Each spurt results in the system moving farther from equilibrium, dissipating more energy, and becoming more organized.

Ecosystem succession is an example of this kind of process. Each successional stage corresponds to one steady-state plateau. The displacement of a previous stage by the next is an

[1] *On high quality energy see also: Ahern, J.E., 1980; Brzustowski, T.A., 1978; Edgerton, R.H., 1982; Moran, M.J., 1982.*

example of a spurt, i.e. a re-organization of the system to a new level of structure, which dissipates more energy.

The form that this self-organization takes is not predictable in advance because the very process of self-organization is by sudden change; it "flips" into new regimes. One of the characteristics of sudden change is that systems may have several possible behavioural pathways available at each flip. Which pathway is followed is often but not always an accident of circumstances.

Thus, in a specific geographical location there is the potential for a number of different ecosystems, communities and species to exist, in addition to the ones currently present. In "classical" ecology, ecosystems (at least those in wilderness areas) were assumed to be in a steady-state when averaged over the long term. C.S. Holling (1973) suggested the analogy of a ball in a hollow. If the ball is given a tap, it moves but never out of the hollow. However, if the tap is strong enough or if the hollow is not very deep, the ball may move over the ridge and into another hollow (achieving a different steady state). By analogy, an ecosystem can be visualized as being stable to small disturbances but not to large ones.

It is also possible that a stable equilibrium point may not exist for a system. Holling (1986, 1992) has given a number of examples of this and suggests that the notion of a steady state is an illusion. Ecosystems are continually undergoing a birth-growth-maturity death process, which he refers to as the exploitation,conservation, release, reorganization cycle. Interrupting this cycle, through for example, forest fire suppression, not only interferes with the normal cycle of life but also magnifies changes when they are eventually triggered.

Movement through the cyclic process, described by Holling, is not continuous. There are temporary stationary states, separated by flips. Furthermore, this behaviour can be extremely sensitive to initial conditions (Levin, 1991). Therefore, elements of the process can be inherently unpredictable.

Some properties of complex systems (including ecosystems) are given in Box 2.2. The key theoretical point is that the normal behaviour of ecological systems is quite complex and the simple notion of succession to a stable climax community is not adequate. Equally suspect is the notion that loss of ecological integrity corresponds to disturbance of the ecosystem away from a climax. Life is not about maintaining stable equilibrium states. It is dynamic and ever-changing. Of particular importance is the fact that complex systems do not always change in continuous and deterministic ways. Also of special importance is the idea that a complex ecosystem contains a library of information. The challenge facing us is to discover what rules, if any, govern the overall direction of ecosystem development and change in response to environmental change.

The evolutionary trajectory of an ecosystem is through a series of temporary "optimum operating points" (Kay, 1991a,b). The word *temporary* needs to be stressed because this point represents a balance between the organizing forces acting on the system and the disorganizing forces of environmental change. As the environment changes, the balance and hence the optimum operating point also change. Of course, there are points in a trajectory that can lead to a future whose development is unpredictable.

Recommendation (2.1): Research into non-equilibrium thermodynamics ought to be one of the centrepiece themes of a Canadian LTERM.

Box 2.2
Properties of Complex Systems (Kay, 1991)

Non-linear: The system behaves as a whole. Cannot be decomposed into pieces and then reconstructed by adding the pieces together.

Multi-scaled: Cannot be understood by focusing on one scale alone.

Window of vitality: Must have enough complexity but not too much. Complex systems strive to stay within a "window" of vitality.

Multiple steady states: No preferred unique steady state.

Dynamically stable: Equilibrium points for the system may not exist.

Catastrophic behaviour: Sudden, dramatic changes. Flip-flops.

Information libraries: Genes

An ecosystem is said to have *integrity* if it is able to survive successfully, i.e. maintain its dynamic self-organization capability, in a changing environment. The properties of an ecosystem that contribute to its integrity include (Kay, 1991, 1993):

- an ability to maintain itself under normal environmental conditions, i.e. *ecosystem health;*

Box 2.3
Loss of Ecosystem Integrity

Kay and Schneider (1992) and Schneider and Kay (1994) have provided an example of ecosystem integrity, based on carbon-energy flows in two aquatic tidal marsh ecosystems in Florida. While one system was used as a control, the other was stressed by a variable hot water effluent from a nuclear power station. In absolute terms, all of the carbon flows in the stressed system were smaller than in the unstressed one, i.e. the stressed ecosystem was consuming fewer resources and degrading and dissipating less incoming energy. The analysis also showed that there was a breakdown in the ability of the stressed ecosystem to recycle carbon through detritus and thus to retain its own supply of carbon; a clear demonstration that the stressed ecosystem had lost some of its integrity.

- an ability to cope with stress, i.e. *stability* and *resilience*;
- a self-organizing ability, i.e. an ability to change when its environment changes.

In short, integrity is about an ecosystem's ability to maintain its functioning — both in the short and in the long term — in the face of a constantly changing environment[2]. In seeking to understand the relationship between ecosystem structure and integrity, comparisons of different types of ecosystems (marine versus forest) or ones located in different parts of the world (Chesapeake Bay versus the Baltic) would not be easy to interpret. Searching for long-term structural changes in single ecosystems, would be more likely to produce meaningful results.

extending from *Exploitation* to *Conservation* (the climax state). In this latter "mature" state, most of the nutrients and energy are locked up in the biomass, and the system gradually becomes brittle. Key structural parts become risk prone, waiting for an accident to happen through fire, wind-storms, pests and senescence (the downward segment from *Conservation* to *Release*). This latter relatively fast process generally occurs in patches, releasing nutrients and energy locally and ultimately permitting the cycle to move on in the figure-eight from *Release* to *Reorganization*. Understanding ecological integrity requires that we understand these figure-eight patterns and the associated patchiness.

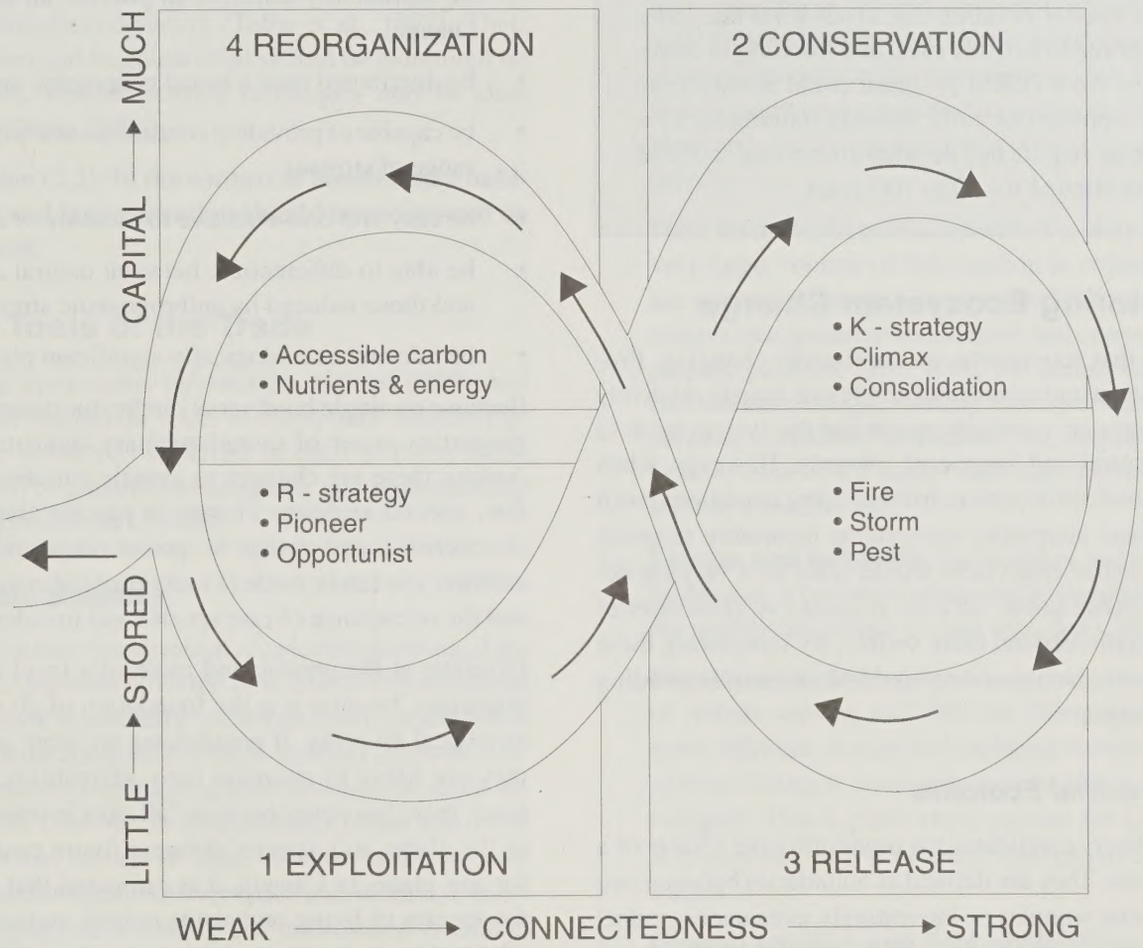


Figure 2.1: The "figure eight" model of an ecosystem (Holling, 1986). The arrows show the speed of the flow of events in the ecosystem cycle, where arrows close to each other indicate fast change and arrows far from each other indicate slow change. The exit from the cycle at the left of the figure indicates the stage where a flip into a greatly modified ecosystem is most likely.

A figure-eight pattern has been used to describe how ecosystems change while maintaining their integrity. Succession (a relatively slow process) is the upward loop in Figure 2.1

The integrity of the system is also maintained through the existence of an information library stored mainly in its genes. Genes contain an historical record of previous successful self-organization, constraining the self-organization of an ecosystem to those options that have a high probability of success (Kay, 1984). Referring to Figure 2.1, the system information library is of most importance at the point of exit from the figure-eight to the left of the figure. This is where a flip into a greatly modified ecosystem is most likely.

[2] *A distinction should be made between temporary shocks and permanent change. In the former case, the system can often absorb the shock through re-organisation, followed by a slow return to its original configuration.*

Box 2.4
Environmental Time Bombs

Under certain circumstances, an ecosystem may undergo sudden change in response to the gradual build up of stresses. In studies of acidifying lakes for example, investigators noticed that even in cases where water bodies were subject to a continuing rain of sulphates and nitrates from the atmosphere, the water pH did not change appreciably over long periods of time. Suddenly, however, the pH would drop sharply. The explanation is that until the buffering capacity of a lake is used up, the pH changes little (Stigliani, 1988). Other examples of potential environmental time bombs include the drainage of wetlands, coastal flooding due to sea level rise, conversion of farmland to other uses, and flooding of abandoned mines. An LTERM program could assist in the design of an appropriate early warning monitoring system, which may require that detailed inventories and field surveys be continued for 50 to 100 years.

2.2 Monitoring Ecosystem Change

We have seen that ecosystems are continually changing. Providing that external environmental conditions remain relatively constant, changes are relatively minor and the system tends to maintain structural and functional integrity. However, when there is a pronounced departure from existing conditions, such as during climate alteration, ecosystems invariably respond. Although the entire ecosystem would react to a varying degree, certain spatial areas, such as *ecotones* or indicators of *biodiversity* might respond more visibly. By monitoring these areas or elements, early warning could be given of impending ecosystem changes.

2.2.1 Terrestrial Ecotones

Ecotones are likely candidates for monitoring the effects of a changing climate. They are defined as boundaries between two distinct vegetation complexes. Interestingly, even under gradual changes of external conditions, the ecotonal boundaries are often distinct and well defined. Ecotonal boundaries between major *biomes* (forest-prairie; taiga-tundra; mountain forest-alpine tundra) are defined climatically and are thereforeprone to early feedback on climatic change.

2.2.2 Biodiversity

Indicators of biodiversity may serve as warnings of ecosystem change. Two points of view have been put forward with respect to the role of individual species in maintaining ecosystem integrity:

- **The airplane rivet assumption.** If species, like rivets in an airplane wing, are removed one by one from an ecosystem, the system will ultimately change radically or even collapse;
- **The redundancy assumption.** A species may be non-essential for an ecosystem under current environmental conditions but it might become critically important if large environmental changes were to occur or when the ecosystem moves to a different stage in the figure 8 diagram.

The effects of environmental stresses on biodiversity are expressed in different ways at different levels of biological organization. Effects at one level can be expected to reverberate through other levels, often in unpredictable ways. Ideally, a biodiversity indicator should have the following attributes:

- be sufficiently sensitive to provide an early warning of change;
- be distributed over a broad geographic area;
- be capable of providing continuous assessment over a wide range of stresses;
- be easy and cost-effective to measure or collect;
- be able to differentiate between natural cycles or trends and those induced by anthropogenic stress;
- be relevant to ecologically significant phenomena.

Because no single biodiversity indicator possesses all of these properties, a set of complementary indicators is required. Among these are changes in genetic variation and composition, *species richness*, change in species abundance, habitat charateristics and change in species range and occurrence. In addition, use can be made of individual *indicator species, guilds* and the occurrence of rare species and invading organisms.

Diversity at the genetic and molecular level is perhaps most important, because it is the foundation of all other aspects of biological diversity. If populations are large and outbreeding, they are likely to maintain their adaptability. At the species level, there has never been an "all-taxa inventory" in any part of the globe, so a species richness figure cannot be obtained for any place. In Canada, it is estimated that roughly half of the species of living organisms remain undescribed. In many circumstances, however, changes in species richness at a given site are not likely to be very instructive. The distribution of species abundance is often a more sensitive measure of environmental disturbance than species richness alone.

Indicator species have been used for decades as a convenient assay for environmental conditions (Thomas, 1972; Zonneveld, 1983). The miner's canary is a classic example of an indicator species. A *keystone species* on the other hand is a species that is essential to the survival of an ecosystem, e.g. a predator that keeps populations of other species, like rabbits, at reasonable levels. Such species have sometimes been promoted as suitable indicators of ecosystem stress (Johnsson, 1993). Since it is impossible to study all species living in an ecosystem at one time, guild concepts enable one to concentrate on specific

groups of species with specific functional relationships (Simberloff and Dayan, 1991). Guilds are defined as groups of species that exploit the same class of environmental resources in a similar way (Root, 1967). The presence of rare species is often an indicator of ecosystem integrity (Keddy et al., 1993). Rare species can be expected to disappearwhen the community is stressed, and some common species can be expected to become rare. Evidence of invading species is generally an indicator of ecosystem stress or change (Keddy et al., 1993). Since virtually all of an ecosystem's functional and structural properties can be strongly influenced by invading species, monitoring of such species may be a useful measure of ecosystem stress or change.

Habitat destruction and fragmentation is one of the main causes of the loss of biological diversity (Tolba et al., 1992). Thus, habitat destruction and fragmentation should be monitored on a long-term basis. Remote-sensing techniques may be ideal for this purpose (Noss, 1990).

Recommendation (2.2): In the context of biodiversity, habitat destruction and fragmentation should be monitored on a long-term basis.

2.3 Some Tools of the Trade

Remote sensing, *geographic information systems* (GIS), and paleoecology are important tools in ecosystem monitoring. Canadians have developed expertise in each of these areas, expertise that will be essential to designing and implementing an ecosystem approach to LTERM.

2.3.1 Remote Sensing

Remote sensing is the measurement of selected portions of the electromagnetic spectrum reflected or re-emitted by terrestrial features. The sensor is normally carried on board an aircraft or satellite. GIS (Geographic Information System) refers to computerized procedures to manage spatial information about the nature of the earth's surface. Both techniques frequently result in the collection and storage of large volumes of data to provide detailed characterizations over space and/or time. Understanding, managing and accessing this information is vital to the success of an LTERM program.

The information obtained may be used to answer questions of connectivity, corridors and networks, spatial relationships, areas, boundaries, edge effects, and so on. With repetitive surveys, the information may also be used to determine changes over time. These tools become integral to LTERM when dealing with large-area issues (e.g. drought in the Great Plains region, phytoplankton blooms in coastal waters, or spruce budworm infestation in New Brunswick forests). Particularly in terrestrial areas not serviced by roads and marine areas not frequented by ships, remote sensing is an extremely valuable tool.

At the same time, the rapid development of technologies and the large volumes of data collected impose substantial barriers for the investigator. The following are some issues of particular relevance to LTERM activities:

- **Data availability:** Many agencies (international, national, provincial and private) are involved in the collection and storage of spatial data in digital form, and currently there is much confusion and duplication.
- **Data access:** Some agencies archive digital data for distribution and re-use (e.g. Statistics Canada). Other agencies collect environmental information for their own needs, with varying degrees of effort to ensure security and integrity. Agencies that store and distribute data usually maintain it over time and document data quality, but they may also charge for and place restrictions on the use of data. Other agencies may choose to release their data (together with data from other sources) but feel no obligation to maintain long-term data banks in consistent, complete and documented digital form to meet the needs of others.
- **Data formats:** In particular with remotely sensed data, a very large volume of information is collected. The data are generally stored in unprocessed form and require extensive manipulation to interpret and convert to true geographic position. Over time, the actual sensor and data formats may change, making time series comparisons increasingly difficult. In addition, the magnetic media used to store some of the earlier data may degrade and become lost for scientific use.
- **Lineage and metadata:** As the types and sources of data proliferate, it becomes increasingly important to determine the quality and origin of data sets. See Chapter 5.
- **Developing technologies:** All aspects of the technologies of remote sensing and GIS are changing rapidly: hardware. software, storage and exchange formats. In the course of these changes, some data may be lost in obsolete technologies. This is particularly serious for LTERM, which is concerned with ecological changes over decades and longer.
- **Ground-truthing and field verification:** Remote sensing technology was developed, in part, because there were insufficient resources to collect information by conventional means. However, while there are large amounts of remotely sensed data, there is inadequate ground-truth information to verify data reliability. Similarly, GIS technology has facilitated the combination of spatial data and maps without regard to scale or reliability. Much of the interpreted data currently in GIS files must be checked in the field for reliability.
- **Natural conditions of data availability:** Even with the current level of technical sophistication, current data collection processes do not produce complete and consistent data sets. For example, clouds interfere with many bands

of remotely sensed data whereas other interferences affect the quality of radar and other radiation bands. Data analyses and comparisons must accommodate these natural variations in data quality and make provisions to massage incomplete coverage.

- **Classification errors:** In some cases, there are problems in objectively classifying the elements in a remotely-sensed picture.

2.3.2 Paleoecology

Another technique for monitoring ecosystem change is paleoecology, which provides an understanding of how terrestrial and limnological systems have responded to past changes in climate. Paleoclimatic data are important in global change studies, yielding (Lorius and Oeschger, 1994; Street-Perrott, 1994):

- Evidence of historical trends in the greenhouse gases and in climate responses. The data show, for example, that there have been rather abrupt climatic events, most strongly marked in the arctic but with reverberations in the tropics;
- Evidence of the effects of historical climates on terrestrial ecosystems. However, care must be taken to ensure that rate of change are comparable.

Figure 2.2 lists the main types of paleoecological data and some of their characteristics. Many of these kindsof data are collected in Canada.

Recommendation (2.3): The Canadian LTERM program should seek close working relations with the paleoecology and remote sensing communities in Canada. In both cases, the human resources and technical support already available will be invaluable.

Archive	Best Temporal Resolution*	Temporal Range (y)	Information Derived
Historical records	day/h	10^3	T, H, B, V, M, L, S
Tree rings	season/y	10^4	T, H, Ca, B, V, M, S
Lake sediments	y to 20 y	10^4-10^6	T, H, Cw, B, V, M
Ice cores	y	10^5	T, H, Ca, B, V, M, S
Pollen	100 y	10^5	T, H, B
Loess	100 y	10^6	H, B, M
Ocean cores	1000 y	10^7	T, Cw, B, M
Corals	y	10^4	Cw, L
Paleosols	100 y	10^5	T, H, Cs, V
Geomorphic features	100 y	10^7	T, H, V, L
Sedimentary rocks	y	10^7	T, Cs, V, M, L

* Minimum sampling interval in most cases.
T = temperature, H = humidity or precipitation, C = chemical composition of air (Ca), water (Cw) or soil (Cs), B = biomass and vegetation patterns, V = volcanic eruptions, M = geomagnetic field variations, L = sea levels, S = solar activity.

Figure 2.2: The main types of paleoecological data and some of their characteristics (Eddy, 1992).

2.4 Conclusions

Ecosystems are complex, and they must be studied in the context of space, time, energy and information. Their behaviour is often not predictable, they are far from equilibrium, and they undergo flip-flops. Ecosystems have a self-organizing ability, which contributes to their integrity, i.e. their ability to adjust to a changing environment. There is growing evidence that ecosystems need to be studied on many space scales, up to and including the continental one, and over time scales from decades to hundreds of years. Of particular importance is the study of *landscape ecology*.

The goal of this proposed program is to evaluate, monitor and predict long-term ecosystem and community changes across several space and time scales, which means that ecological assessments over hundreds to thousands of kilometres and hundreds of years will be necessary.

Recommendation (2.4): Ecosystems need to be studied on many spatial and temporal scales (from local to continental, and from decades to centuries). Of particular importance is the patchiness of ecosystems, so that the landscape scale needs to be emphasized.

Recommendation (2.5): The ecosystem approach described in this chapter allows us to recommend a number of key research topics for a Canadian LTERM program:

- Studies of the relationships amongst biodiversity, ecosystem functioning and ecosystem integrity;
- The application of non-equilibrium thermodynamics to ecosystem functioning and integrity. This ought to be a centre-piece theme of the Canadian LTERM program;
- Studies of ecotones. These provide special opportunities to examine the effects of discontinuities on ecosystem functioning. They also may be particularly useful as early indicators of global change.
- Environmental time bombs. Ecosystem functioning may sometimes be threatened over the long term by minor but accumulating stresses, and the ultimate result may be a sudden and surprising disfunctioning of the ecosystem involved.

Chapter 3
Global Change and the Canadian Environment: Scenarios for the 21st Century

In the second half of the 20th century, there were many examples of unexpected happenings: the fall of the Berlin wall, the launching of the first satellite, the discovery of the stratospheric ozone hole over the Antarctic, and the rapid growth of cities such as Toronto and Vancouver. In the 21st century, there is a possibility of unprecedented rates of change, especially in the global geophysical/ecological environment.

3.1 Socioeconomic Sources of Ecological Change

Tracing back the causes of ecological change, the root reasons for these changes frequently lie in the realm of socioeconomics, often with time lags of decades or longer. Thus to understand long-term ecological changes, and to simulate future conditions, LTERM programs must include a strong socioeconomic component.

Some of the stresses on ecosystems are, for example, high tropospheric ozone levels, acidic deposition and excess UV-B radiation. Often, however, these "immediate" factors are symptomatic, and the underlying stresses are socioeconomic. For instance, population growth and over-consumption have placed enormous stress on ecological life-support systems (loss of prime agricultural land, over-consumption of fresh water, increased production of wastes, increased energy consumption). Other socioeconomic changes that might surprise us in the 21st century include

- technology developments (including information technology);
- medical breakthroughs, increasing life expectancy;
- plagues and famines;
- a global environmental refugee population exceeding 500 million (due to sea level rise, droughts, etc. with enormous political pressure on Canada).

Thus, in order to provide very early warnings of impending losses in ecosystem integrity, it is often useful to supplement biogeophysical with socioeconomic monitoring. For example, monitoring of trends in ozone episodes is essential but because of natural variability, it may be more useful to monitor underlying causes such as energy consumption, sale of automobile air conditioning systems, etc. See Figure 3.1 for a list of socioeconomic indicators that might be considered in studies of ecosystem integrity.

Recommendation (3.1): The Canadian LTERM program should include a socioeconomic component, whose goal is to permit an integrated approach to investigations of the socioeconomic causes and consequences of long-term ecological change.

A: General Indicators

1. State of health of natural ecosystems (primary productivity, efficiency of nutrient recycling, species diversity, population fluctuations, prevalence of pests, etc.) (Rapport 1989)
2. Resilience indicators (biodiversity, spatial patchiness, etc.)

B: Indicators of Threats to Ecosystem Integrity

1. Increasing population (especially urbanization)
2. Increasing energy consumption (type, per capita and total amounts, energy required to produce a unit of manufactured goods, etc.)
3. Increasing consumption of water (per capita and total)
4. Rates of depletion of renewable and nonrenewable resources (forests, prime agricultural land, mineral reserves, etc.)
5. Increasing amounts of wastes
6. Transportation indicators (number of cars, kilometers of road, number of airline passengers, etc.)

C: Indicators of Reduced Threats to Ecosystem Integrity

1. Increasing output of production per unit of natural resources used (both renewable and nonrenewable)
2. Increasing extent of recycling efforts
3. Conservation of scarce or highly valued resources (endangered species, wilderness, historical monuments, etc.)
4. Declining sales of pesticides and herbicides
5. Declining economic and energy subsidies given to the natural resource sectors
6. The degree of citizen involvment in "environmentally friendly" actions

Figure 3.1: Socioeconomic indicators that could be monitored in the context of ecosystem integrity and sustainability (Munn, 1993).

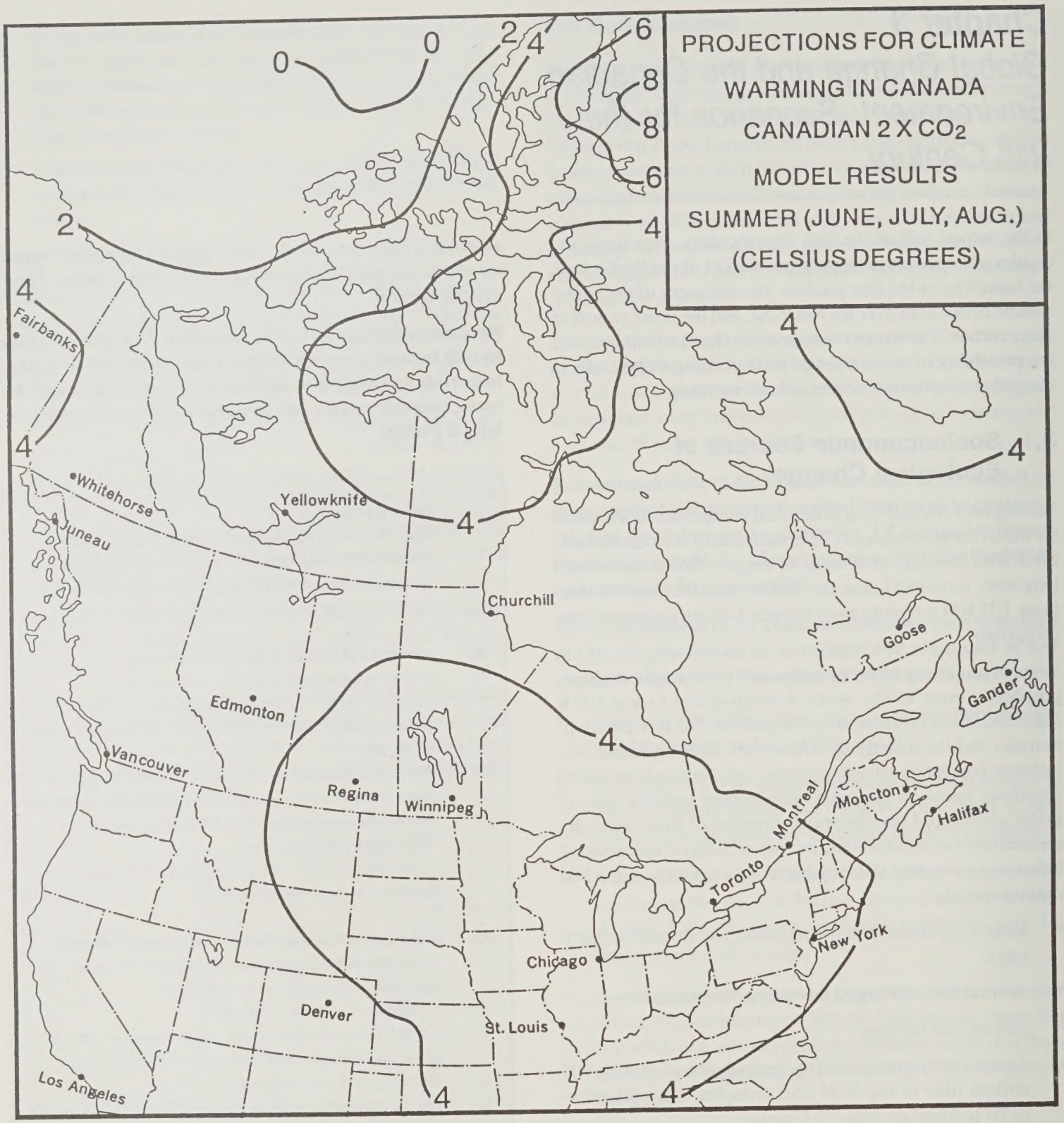


Figure 3.2 Simulations for climate warming for Canada for a doubling of greenhouse gases from their pre-industrial levels: winter (CCPB, 1991). The isopleths in degrees Celsius are increases in temperature above current values.

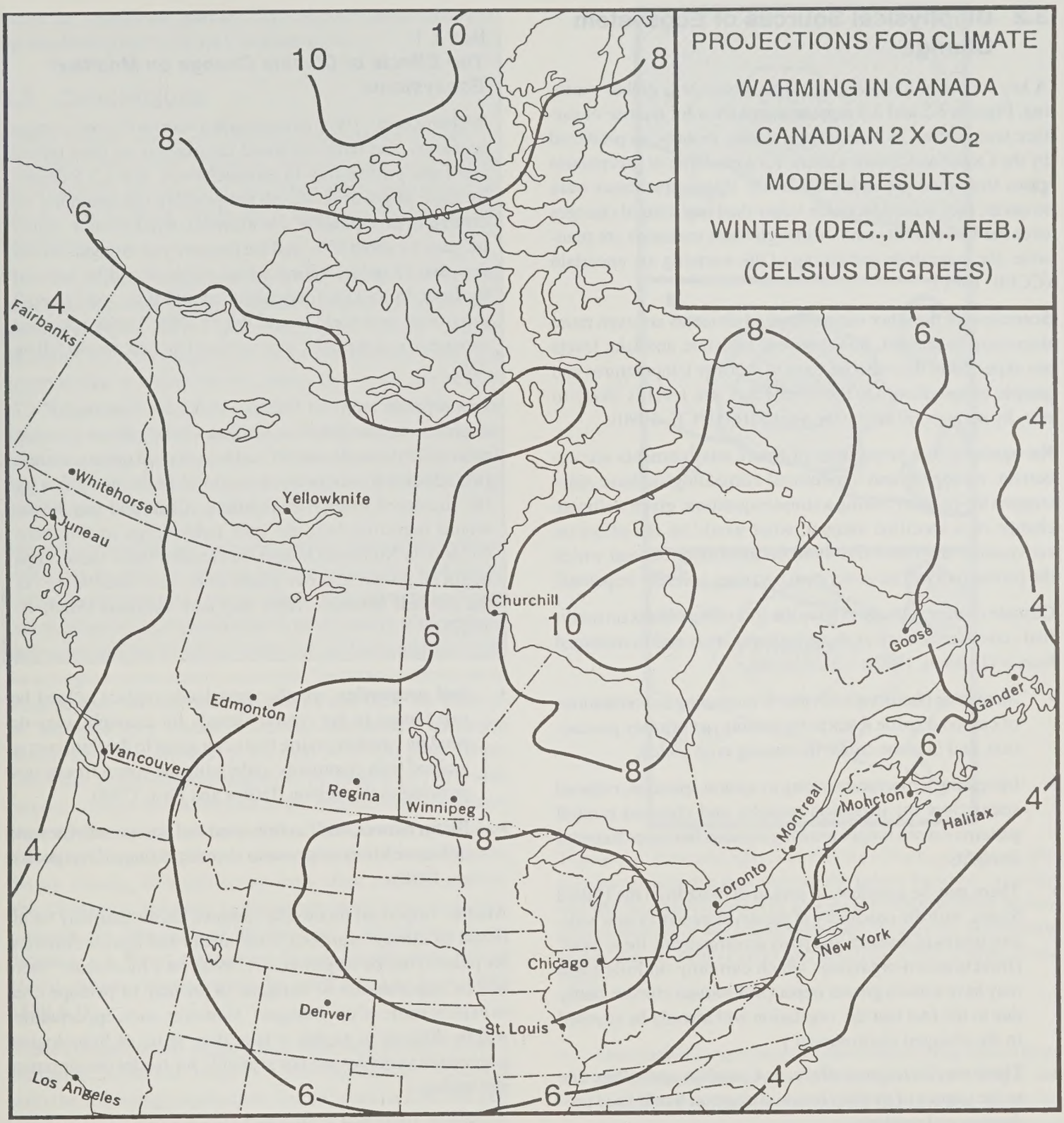


Figure 3.3 Simulations for climate warming for Canada for a doubling of greenhouse gases from their pre-industrial levels: winter (CCPB, 1991). The isopleths in degrees Celsius are increases in temperature above current values.

3.2 Biophysical Sources of Ecosystem Change

A key source of long-term ecological change is global warming. Figures 3.2 and 3.3 represent scenarios for the rise of surface temperature in summer and winter months, as predicted by the Canadian Climate Centre, for a doubling of greenhouse gases from their pre-industrial levels. If these increases were to occur, they would be much larger than any natural changes over the last 10,000 years. Although these scenarios are plausible, the magnitude and timing of the warming are uncertain (CCPB, 1991).

Scenarios for the other meteorological elements are even more uncertain. In general, however, soil moisture and lake levels are expected to decrease because of warmer temperatures and greater evaporation. On the other hand, sea level is likely to rise, by perhaps 60 cm by the year 2100 (IPCC, 1990).

Recognizing that projections of future environments are uncertain, ecologists and agricultural climatologists have sidestepped the issue by asking a simpler question: given a climate change of a specified amount, what would be the effect on ecosystems and can a threshold be identified, beyond which the productivity of an ecosystem becomes severely impaired?

Climate change is likely to have the following effects on modified ecosystems, such as in agricultural areas and in managed forests (Jackson, 1992):

- Increasing photosynthesis due to increasing concentrations of carbon dioxide leads to increasing net primary production, and in some cases, increasing crop yields;
- Increasing temperature, rising evapotranspiration, reduced streamflow for irrigation projects and changed rainfall patterns causes longer growing seasons but more frequent droughts;
- There may be a northward spread of biota from the United States, with the possibility of the development of new virulent strains of diseases and pests accompanying these biota. [Insects/micro-organisms which currently do little harm may have a much greater impact in a warmer climate, partly due to the fact that the vegetation will already be stressed in the changed environment.]
- There may be indirect effects on Canadian agriculture due to the impact of global climate change on world food production and markets;
- There will be increasing frequencies of forest fires if the climate becomes drier.

In relatively undisturbed areas, major shifts are expected in the location and character of existing ecosystems as a result of increasing greenhouse gases (Rizzo and Wiken, 1992). Figure 3.4 shows how climatic change could affect the range of species occupying a hypothetical Biosphere Reserve. Future distributions of plant assemblages will be influenced by several factors including:

Box 3.1
The Effects of Climate Change on Modified Ecosystems

Williams et al. (1988) have assumed various climate-change scenarios, and have estimated the impacts on farm output and farm profitability in Saskatchewan. For a 3.5 degree increase in growing-season temperature but assuming no change in precipitation, for example, wind erosion would increase by about 25%, and the frequency of droughts would increase 13 times. Spring wheat yields would be reduced by from 15 to 37% (depending on soil type), and overall provincial crop yield would fall by 28%. Under specified economic assumptions, average farm income would fall by 12%.

In a separate study of Ontario, a climate warming of 1.7 degree and a precipitation increase of 45% in the growing season, for example, would lead to increased moisture stress (the additional precipitation would be more than offset by the increased evapotranspiration). Corn and soyabeans would therefore become very risky crops in Southern Ontario; in Northern Ontario, on the other hand, these crops might be grown in areas where soils were suitable, i.e. in the claybelt between North Bay and Timmins (Smit, B. 1987).

- **Soil properties**; whether grasslands replace upland boreal forests in the central Canada for example, may depend on whether prairie biota can adapt to the thin, coarse-grained soils commonly underlying the boreal forests now growing in this region (Pastor and Post, 1988).
- **Disturbances**, such as fire, wind and human activities will influence forest response to climatic change (Overpeck et al., 1990).

Another important renewable resource sector that may be affected by climate warming is the inland and marine fisheries. As pointed out by Regier et al. (1990), on a local scale "there will be opportunities to mitigate, to prevent, or perhaps even to exploit some of the changes." However, such opportunities will be difficult to exploit if long time series of limnological and related variables are not available for model development and testing.

A separate issue that is already becoming important is stratospheric ozone depletion, which is a special kind of climate change. A reduction in stratospheric ozone leads to an increase in UV-B radiation reaching the earth's surface, which may damage humans and ecosystems. Most attention has been directed towards the Antarctic stratospheric "hole" but there is recent evidence of ozone depletion in polar regions of the Northern Hemisphere. For instance, UV-B induced damage to lichen has been reported in Greenland (Johnsen and Heide-Jørgensen, 1993). Because lichen is an important food for caribou and reindeer, the long-term implications for Canada's Inuit popu-

lation are significant, and an LTERM component should be initiatedimmediately in the Canadian arctic.

3.3 Conclusions

Global change would certainly have significant impacts on Canadian ecosystems. There is, nevertheless, considerable uncertainty in this assertion, as climatologists and ecologists are the first to admit. There are at least two reasons for this uncertainty.

First, the driving forces causing environmental change are largely socioeconomic, e.g. population growth (of both people and automobiles), energy consumption, the "mining" of natural resources, technological advances and cultural shifts. The uncertainties in socioeconomic projections over the next 50 to 100 years are substantial, and — in some small ways at least — the projections can be modified by the corrective actions of society. For this reason, futurists usually consider a range of possible socioeconomic scenarios, trying to design policies that keep options open.

Secondly, the world environment, and the array of ecosystems contained therein, are almost infinitely complex with many feedbacks operating on several widely different time and space scales. Because it is not possible to model many of these intricacies, projections of future conditions will be uncertain, even for a single socioeconomic scenario. Uncertainty increases as the time span into the future lengthens, and there are likely to be "surprises" (e.g. a burst of volcanic eruptions, or a massive worldwide forest dieback) in the next 50 to 100 years. There could also be flip-flops as suggested by Broecker (1987) with respect to major ocean currents in the Atlantic that would have tremendous impacts on ecosystems. These can be understood (but not predicted) in terms of non-equilibrium thermodynamic theory. Finally, although ecosystems often undergo predictable changes in response to alterations in their external environment, the time scale of the response is sometimes unpredictable; e.g. forest ecosystems lagged significantly behind global climate change during the Little Ice Age from 1200-1850 A.D.

These considerations suggest that long-term policy for environmental protection requires a risk-management approach with the following implications for a Canadian LTERM program:

- A long-term perspective on ecosystem behaviour is essential;
- A global view on the causes of environmental/ecosystem changes must be promoted;
- These global-scale changes will affect regional environments, and long-term ecosystem research will be the better if it is undertaken in the context of processes operating at larger time and space scales;

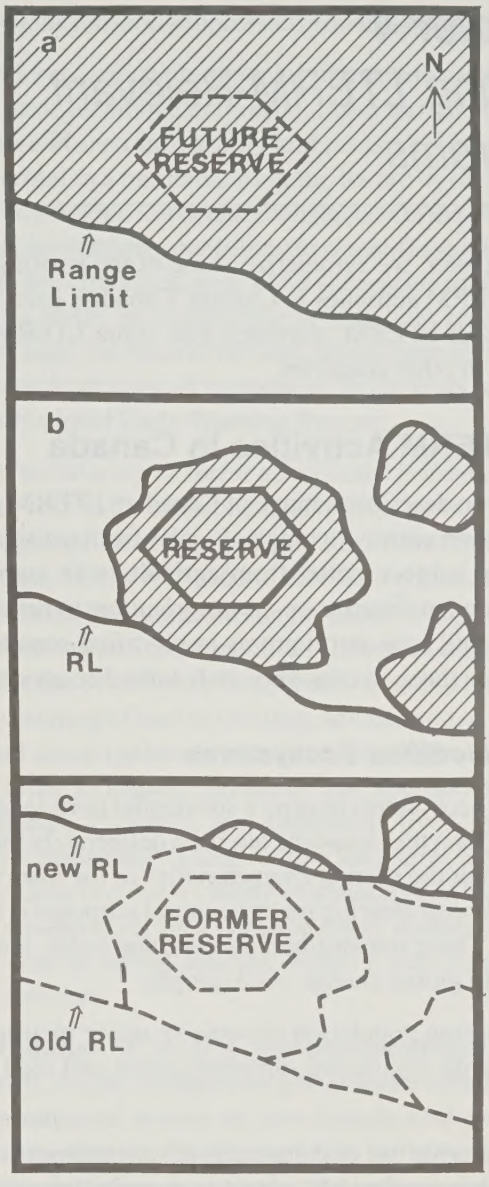


Figure 3.4: Potential effects of shifting climatic ranges on species occupation of a hypothetical Biosphere Reserve: (a) original species distribution; (b) species distribution after human fragmentation of the landscape; and (c) species distribution after climatic shift (Peters and Darling, 1985; Urban et al., 1992).

- One goal of long-term ecosystem monitoring should be to provide early warning of increasing rates of change, and indeed of flip-flops. Because these changes may be caused by socioeconomic events originating at a variety of space and time scales, a very broad perspective must be maintained.

Recommendation (3.2): It is further recommended that the development of early warning indicators of long-term global change be given particular attention within this program. This will of course involve model development, field experiments and the establishment of long-term monitoring programs. Special attention should be given to UV-B monitoring in the arctic.

Chapter 4
Existing LTERM-Relevant Programs

In this chapter, we summarize some of the existing and proposed LTERM activities in Canada, Canada's participation in international LTERM activities, and some LTERM relevant activities in other countries.

4.1 LTERM Activities in Canada

This section describes a range of Canadian LTERM programs. The selection portrays a range of scales from national to local, a range of subject matter from agriculture to marine, and a range of human disturbance, from agriculture to national parks. First, we will look at programs in modified ecosystems and then turn to those in relatively undisturbed ecosystems.

4.1.1 Modified Ecosystems

Modified ecosystems occupy a substantial portion of southern Canada. Often the landscape has been deliberately transformed so as to alter the normal characteristics of the associated ecosystems. Forest clearing for agricultural purposes is the classic example. These transformations continue today, and are contributors to global change. As examples:

- increasing population pressure in major metropolitan areas, with continuing suburbanization and road construction;
- world-wide use of industrially-fixed nitrogen as fertilizer, which is now roughly equal in magnitude to the nitrogen fixed naturally;
- fragmentation of landscapes, reducing suitable habitat for species that dwell within forest interiors; and
- drainage of freshwater and coastal wetlands, with corresponding alterations in hydrologic regimes, nutrient retention capacities, and reduction of habitat for fish.

Settlement Areas

In keeping with their greater economic value and potential for inadvertent damage, ecosystems in settlement areas are the subject of considerable research and monitoring. Studies of areas facing development pressures (such as the construction of a shopping centre) are frequently undertaken for purposes of environmental impact assessment. Unfortunately, these studies are generally short-term and are usually designed to characterize the ecological effects of a single deliberate change in the landscape. Consequently, the ecological data generally consist of basic resource characterization and short-term monitoring of incremental effects.

Two of the few exceptions to this state of affairs can be found in the city of Kitchener (Kay, 1994) and along the Niagara Escarpment (Kay, 1994; Regier et al., 1994), where long-term environmental management policies are being designed based on the ecosystem approach. Using the Kitchener (Huron Park) study as an example, the organizing principles and system perspectives are shown in Box 4.1. Of particular importance are the energetics that relate to ecosystem functioning. From this perspective, the important biological processes are nutrient flows, biomass production and food webs. With respect to nutrient flows, special attention is being given to detrital flows.

Recommendation (4.1): There have been many short-term studies of urban ecology, but there have been few LTERM-related programs in the urban environment. Therefore, it is recommended that urban ecosystems be given research attention comparable to that given agricultural, forest and other less modified ecosystems.

Box 4.1
Organizing Principles and System Perspectives Used to Describe the Environment of the Huron Park Environmental Area (Kay, 1994)

Organizing principle	*System perspectives*
Abiotic	Air sheds Watersheds Geomorphology
Biotic	Wildlife (species) Communities Landscape
Cultural	Human use of land Cultural and historical significance
Energetics	Energy flows Nutrient cycling

Agroecosystems

For agroecosystems, ongoing monitoring of basic environmental parameters is in progress at agricultural research stations and experimental farms managed by Agriculture Canada (Agriculture Canada, 1992). A new initiative is the Soil Quality Benchmark Sites program of Agriculture Canada, a coordinated national program that was established to monitor changes

in soil and environment in major agroecosystems across Canada.

Research and monitoring are also carried out at colleges of agricultural technology, run by several provincial governments and the eight universities with agricultural faculties. These stations have ongoing research programs aimed at investigating current agroecosystem problems. The colleges also have long-term records of past cropping and other management practices. The Breton plots managed by the University of Alberta have the longest such record, dating back to 1930 (Izaurralde et al., 1993). However, data collection methodologies have changed over the years to reflect evolving crop varieties and management practices.

Recommendation (4.2): Considering the importance of sustainable agriculture and forestry to Canadians and Canadian export markets, and considering the importance of soils and soil processes to ecosystems, it is recommended that the Soil Quality Benchmark Sites program be incorporated into a Canadian LTERM program.

4.1.2 Unmodified Ecosystems

No part of the Earth's surface remains entirely free from the effects of human activity. Compared to most developed countries, however, it is relatively easy in Canada to find research and monitoring sites that arefree from deliberate land use or land cover changes, isolated from local and often regional perturbations such as agricultural or silvicultural pesticide use, and yet accessible for visits by scientists and technicians. Most of the LTERM programs currently under way in Canada are sited in relatively undisturbed forest, tundra or marine ecosystems.

Forest Ecosystems

Forestry research and monitoring is long-term in nature, because trees have life spans in the range of decades to centuries. Forestry scientists are fortunate that trees in the temperate and boreal forest regions preserve a record of annual growth. At the simplest level, this allows an examination of the relation between tree age and other properties such as height, volume, and so forth. Height-over-age curves have for many years been used to indicate differences in productivity among forest sites. Variations in annual growth rings may also be analyzed using complex mathematical techniques that can yield important inferences about past climates.

An interesting early application of dendrochronology was made by Linzon (1961), who studied Jack Pine tree-rings near a CPR round-house at Chalk River, Ontario. Locomotive dispatch figures available from 1927 through the 1950s reflected the economic state of Canada during the period of record — the boom in the 1920s, the slump in the 1930s, and the wartime and post war-time booms of the 1940s. The annual wood increment reflected this railway activity, showing suppressed growth in the 1920s due to increased air pollution, recovery in the 1930s when emissions fell, and suppressed growth again in the 1940s.

The use of long-term study plots, or permanent sample plots, is another basic technique in forestry. Long-term plots provide a link between forest monitoring and research. If tree growth remains normal in a particular plot, the record of observations may have no research importance whatever. On the other hand, permanent plot data may contribute to scientific studies of acid rain, herbivory, climate change, plant succession and competition, and so forth. In recognition of this dual research and monitoring role, the federal forestry department recently created a national network of permanent forest plots, called the Acid Rain National Early Warning System.

Long-term monitoring of forest ecosystems is used to set sustainable harvest levels on public lands, ensuring that society is getting an appropriate return on leases and sales of timber rights (Hendrickson, 1992). It is used to calculate returns on investment for different planting and site preparation regimes, fertilizers and thinning prescriptions. Insect densities are monitored to determine the need for, or the effectiveness of control strategies and planning of tree harvesting. Monitoring of fire probabilities and actual outbreaks is practiced throughout Canada's forests in order to respond promptly and appropriately when valuable timber resources, and sometimes lives and private property, are threatened. These routine long-term forest monitoring programs involve a variety of methods and tools, ranging from ground-level observations using diameter tapes to the processing of digital satellite imagery with sophisticated computer software.

Recommendation (4.3): It is recommended that forestry departments, forest companies and schools collaborate to institute a national system of tree sample and permanent plot data repositories. To support this initiative, research should be undertaken on criteria and indicators.

Tundra

Tundra is the largest and the youngest biome in Canada. Most of the Canadian tundra is underlain by permafrost, which in the highest latitudes extends very deep and even in summer, is close to the ground surface. Proceeding northward from the tree line, plant density, cover and productivity gradually diminish, in tandem with the increasing severity of climate and shortening of the growing season. Tundra of the highest latitudes is almost free of any vegetation. These barren lands are called "polar deserts" (Bliss et al., 1984).

In some sheltered valleys and lowlands, with more favourable mesoclimate, more lush local ecosystems have developed (Svoboda and Freedman, 1994). Their plant and animal diversity is much richer, and their productivity is many times higher than surrounding areas. They function as primary food sources for muskoxen, Peary caribou, hares and wolves, and are preferred nesting sites for numerous bird species. Polar oases also serve as regional refuges during climatic down-turns and as centres for seed dispersal into the adjacent polar deserts.

Due to operational difficulties, Canada undertakes little continuous ecological monitoring in the Arctic. However, because the greatest greenhouse warming is expected to occur in the arctic, the establishment of LTERM facilities in tundra regions must be given the highest priority.

Recommendation (4.4): It is imperative to establish and support a long-term monitoring and research program that would follow structural and behavioural changes in several selected tundra sites. Information obtained will establish a reference base, against which all future changes will be compared. It will also assist in formulation of northern social, demographic and economic policies, and in management of renewable resources.

Marine Ecosystems

Canada has a long history of monitoring elements of its marine areas. In 1893, a federal Board of Management for fisheries and marine research was established. Major oceanographic expeditions of the Pacific, Atlantic and Arctic were undertaken in-1910-1920. Oceanographic work increased during and after the Second World War. This led to the establishment of separate marine science branches and facilities in the late 1950s and early 1960s. Work done during these early years provides a basis for many of our biological and physical oceanographic records.

Today, monitoring marine ecosystems requires information at various time scales and at various spatial scales. The time and spatial scale required depends upon what question is being asked. The objective for most marine ecosystem monitoring is to determine the ocean climate and marine environmental trends, and their impacts on the fishery. Scales that are significant for maritime ecosystems are quite different from the scales relevant to terrestrial ecosystems.

Marine monitoring is conducted in two main categories, biomass and environmental conditions. Marine biomass surveys are the basis for management of the fishery. They include pelagic, anadromous and ground fish, marine invertebrates and mammals, and plants in the Atlantic, Pacific and Arctic Oceans of Canada. Given the close correlation between fish productivity and phytoplankton productivity, plankton has become a standard marine index. This includes quantitative and qualitative abundance of phytoplankton, interannual variations and long-term trends. Monitoring covers the nature and extent of effects on fish health due to bacterial and chemical contaminants, and toxic substances. Marine mammal population size, age, distribution, movement and health are periodically monitored using a variety of techniques, including catch statistics and tissue sampling, airborne survey and satellite tagging.

To carry out environmental monitoring of the physical and chemical properties of the sea and the air above it is necessary: to explore the effects of environment on distribution, growth and recruitment of various fish stocks; to understand climatic changes in the ocean environment; and to identify oceanic influences on marine life and global climate. Monitoring is conducted at regularly re-visited stations and transects, at current-metermooring sites, and by measuring conductivity, temperature, salinity and oxygenation during most research and fisheries surveys. There are approximmately 1,000 stations distributed across Canadian waters.

Two attempts at integrated marine research and monitoring are OPEN, the Ocean Productivity Enhancement Network, and the La Perouse/MASS (Marine Survival of Salmon) Project (National Climate Advisory Committee, 1992). OPEN brings together fisheries biologists and oceanographers from government, private sector and universities in an integrated research program. The initial focus of the program has been on two species of great commercial value, the sea scallop and the Atlantic cod. Using these as models, scientists investigate the processes that control the survival, growth, reproduction and distribution of fish and shellfish.

The La Perouse/MASS project is a multi-disciplinary, multi-species investigation that supports long-term management of fish stocks off the west coast of Vancouver Island. Initiated in 1985, the primary focus of the La Perouse/MASS program has been directed toward describing and understanding the causes of annual and interannual variability of fish and zooplankton stocks over the La Perouse Bank on the southwest portion of the shelf.

Pollution, resource harvesting and other uses of marine ecosystems are giving rise to management challenges that are beyond our current knowledge base. Management of marine resources needs information from long-term ecological monitoring. This requires the establishment of multidisciplinary marine programs to enhance existing data collection activities carried out over the last several decades.

Integrated monitoring of Canada's Pacific coast ecosystems has been initiated as part of a proposed marine ecosystem monitoring network (Wilson et al. 1994). The network, based on existing monitoring information, integrates time series monitoring by several agencies university researchers to determine the condition and trends of key attributes of marine ecosystems. System attributes examined include contaminants, pathogens and disease prevalence, species diversity, size and size spectrum of important species groups, primary productivity and nutrients and water column instability. Internationally, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) has finalized the Guidelines for Marine Environmental Assessment, which include considerations for the design of marine monitoring programs applicable to Canada's marine territory (IMO 1994).

Recommendation (4.5): Marine areas should be included in a Canadian LTERM network. This shoud be done by building on existing marine ecosystem monitoring programs and by developing them to reflect the hierarchies within Canada's various marine ecozones.

National Parks

Canada's 36 national parks are established under federal jurisdiction to protect representative natural areas and to allow for their appreciation and enjoyment by present and future generations of Canadians. The system includes all geographic extremes of Canada. Canada has also begun a system of national marine parks: one has been established, another is close to being established, and two large marine areas within existing national parks may be redefined as marine parks. The creation of a national park protects what is there from logging, agriculture, urbanization and other direct uses of the land. Each park is managed according to a process that includes a *resource inventory*, typically involving topographic, hydrographic, landform, soils and vegetation maps, check lists of plant and animal species, and studies of geological history, climate, plant communities, key wildlife populations and archaeological and cultural resources. The national parks therefore meet at least two criteria commonly associated with the selection of LTERM sites, namely long-term protection and availability of baseline data.

Monitoring in national parks consists of a wide array of programs including: weather and air quality; river flows; snow depths; shore erosion; forest succession, insect and diseases; fire and fire weather; fish species and catches, many aspects of wildlife ranging from surveys of breeding birds to radio-tracking of snakes; visitor use and acid rain impacts.

The 1988 National Parks Act calls for regular State-of-Parks Reports, and for maintenance of ecological integrity to be given priority in any decision concerning park zoning or visitor activities. The Parks Canada policies and strategic plan also emphasize the need for research and monitoring as a basis for ecosystem management. Among several initiatives to meet this goal, Parks Canada is developing an ecological monitoring strategy for national parks that will identify core, common measures for all parks, general types of measures that would vary in detail between parks, costs and personnel needs, linkages to other agencies and data management.

Recommendation (4.6): There has been a wealth of ecosystem information collected for national park management, but the localized nature of the studies has resulted in a lack of standardization in methodology and data structures, both between parks and between study repeats. It is therefore recommended that Parks Canada institute a process of ecological data standardization and dissemination, in the context of LTERM.

Recommendation (4.7): National Parks are established in law to protect representative examples of Canada's natural ecological diversity. This makes them ideal sites for LTERM, especially in light of the prospect of being able to repeat studies decades or centuries hence. However, landscape modifications for research purposes are not permitted in national parks. Therefore, it is recommended that portions of national parks be set aside for the purpose of establishing benchmark or reference LTERM sites, where ecological manipulations could be undertaken.

4.1.3 Federal Initiatives on LTERM

The Canadian federal approach to reporting on the state of Canada's environment has changed from a sectoral approach to an ecologically-based one. This has led to a-re-orientation in methodology and the development of new tools and procedures, not only within Environment Canada, but also within other government departments. To integrate basic socio-economic and environmental data more closely, Statistics Canada, for example, is using Canada's *ecozones* for analyzing socio-economic information (see Figure 4.1). Statistics Canada is also developing several new components for the System of National Accounts to impute values to natural resource flows and environmental protection.

Canadian federal initiatives on LTERM monitoring include:

- the establishment of a GIS data base;
- the refinement of a multi-tiered and spatially-based ecosystem classification of terrestrial and marine areas;
- the selection of "intensively monitored" research sites in representative ecosystems.

Ecozone-based Ecological Science Centres (ESCs) are being created, focussed on long-term ecological monitoring and research (marine and terrestrial, including freshwater), and their research is to include human beings as an integral component of ecosystems. Specifically, the centres will be concerned with:

- ecosystem composition, structure, function and process;
- ecosystem history and current state;
- the causes and ecological consequences of environmental change;
- rates of change.

The centres are to be built on existing strengths in federal and provincial agencies, universities and NGOs. They will foster and facilitate cooperative ecosystem research, monitoring and synthesis through alliances among social and environmental scientists. An ESC will coordinate ecological monitoring and research of its ecozone. Each ESC will have at least one representative LTERM site. Each ESC will set its own research agenda within the overall objective of gaining greater understanding of ecosystem function and process. Energy flows, material cycling, population dynamics, and biodiversity are major components to be studied, and changes in rates or composition over time are to be monitored. ESCs will form the backbone of the Canadian ecological monitoring and research initiative, and will be linked in a national network. ESCs will also be linked to similar international programs.

When the program is fully implemented, ESCs will be the focus for continuing LTERM in Canada. Within their ecozones, ESCs will be a source of knowledge for local, regional, and

national audiences. Public participation and education programs will be part of their mandate; indeed, the relevance and credibility of the information they provide will be essential for their survival. An ESC is being established in the Atlantic Maritime Ecozone, and other ESCs are in the planning stage. A national coordinating office has been established within Environment Canada.

It is interesting to note that a marine ecozone classification for Canada has been proposed; see Figure 4.1. This could provide a basis for the design of a comprehensive marine ecological monitoring system for Canada's coastal and inland waters.

4.2 Canada's Role as a Participant in International Programs

Canada contains a significant fraction of the Earth's land and water surface, as well as an important number of ecosystems representing several climatic zones — polar to temperate, and maritime to desert. Canadian participation is therefore not only desirable but also almost essential to the success of the international programs. Here several of the most significant programs are reviewed, and Canadian participation is highlighted.

Recommendation (4.8): Canada contains a significant fraction of the Earth's land and water surface. Thus Canadian participation in international terrestrial and marine ecological programs, particularly IGBP/GCTE, should be given high priority.

4.2.1 International Geosphere-Biosphere Programme (IGBP)

The IGBP is a coordinated global attempt to improve understanding of the interactive atmosphere-ocean-biosphere system. The need for better understanding of the terrestrial biosphere has been recognized by IGBP, which has a Core Project on Global Change and Terrestrial Ecosystems (GCTE) (IGBP, 1992). The objectives of GCTE are:

- to predict the effects of changes in climate, atmospheric composition and land use on terrestrial ecosystems, including agricultural and production forest systems, and on ecological complexity;
- to determine how these effects lead to feedbacks to the atmosphere and the physical climate system.

Box 4.2 summarizes the components of GCTE and gives an idea of the far-reaching program being organized. Recently, the GCTE decided to establish an international system of transect studies (IGBP, 1993; GCTE, 1994). Four major regions, each crossing a transition, have been identified for study: tundra-boreal; semiarid-tropical savanna; temperate forest-prairie; and humid-dry tropical forest.

Other Core Projects of IGBP complement GCTE, and are of relevance to the Canadian LTERM program. These include:

Box 4.2

Components of the IGBP Core Project on Global Change and Terrestrial Ecosystems (IGBP, 1992)

Focus 1: Ecosystem physiology

- effects on the biosphere of elevated levels of carbon dioxide
- terrestrial biochemistry, e.g. the boreal forest as affected by climate change
- effects of changes in vegetation on water and energy fluxes

Focus 2: Changes in ecosystem structure

- patch-scale dynamics
- models from patch to region
- regional-to-global models of vegetation change.

Focus 3: Global change impact on agriculture and forestry

- effects of global change on key agronomic species
- effects of global change on pests, diseases and weeds
- effects of global change on soils
- integrated experimental and modelling program on multi-species agricultural systems.

Focus 4: Global change and ecological complexity

- effects of biodiversity and ecological complexity on ecosystem function
- interactive effects of global change on biodiversity and ecological complexity
- consequences of global change for the viability of isolated populations.

- Biospheric Aspects of the Hydrological Cycle (BAHC)
- Land-Ocean Interactions in the Coastal Zone (LOICZ), which contains the two themes: the role of ecosystems in determining coastal geomorphology, and cycling of organic matter within coastal ecosystems
- Past Global Changes (PAGES)
- Data and Information Systems (DIS)
- Land Use/Land Cover Change (LUCC)
- Joint Global Oceans Flux Study (JGOFS).

Canadian ecologists have contributed in major ways to the understanding of ecosystems, although the individual efforts have often been relatively spontaneous and short-term. GCTE provides a much desired national focus for long-term large-scale ecological research and monitoring.

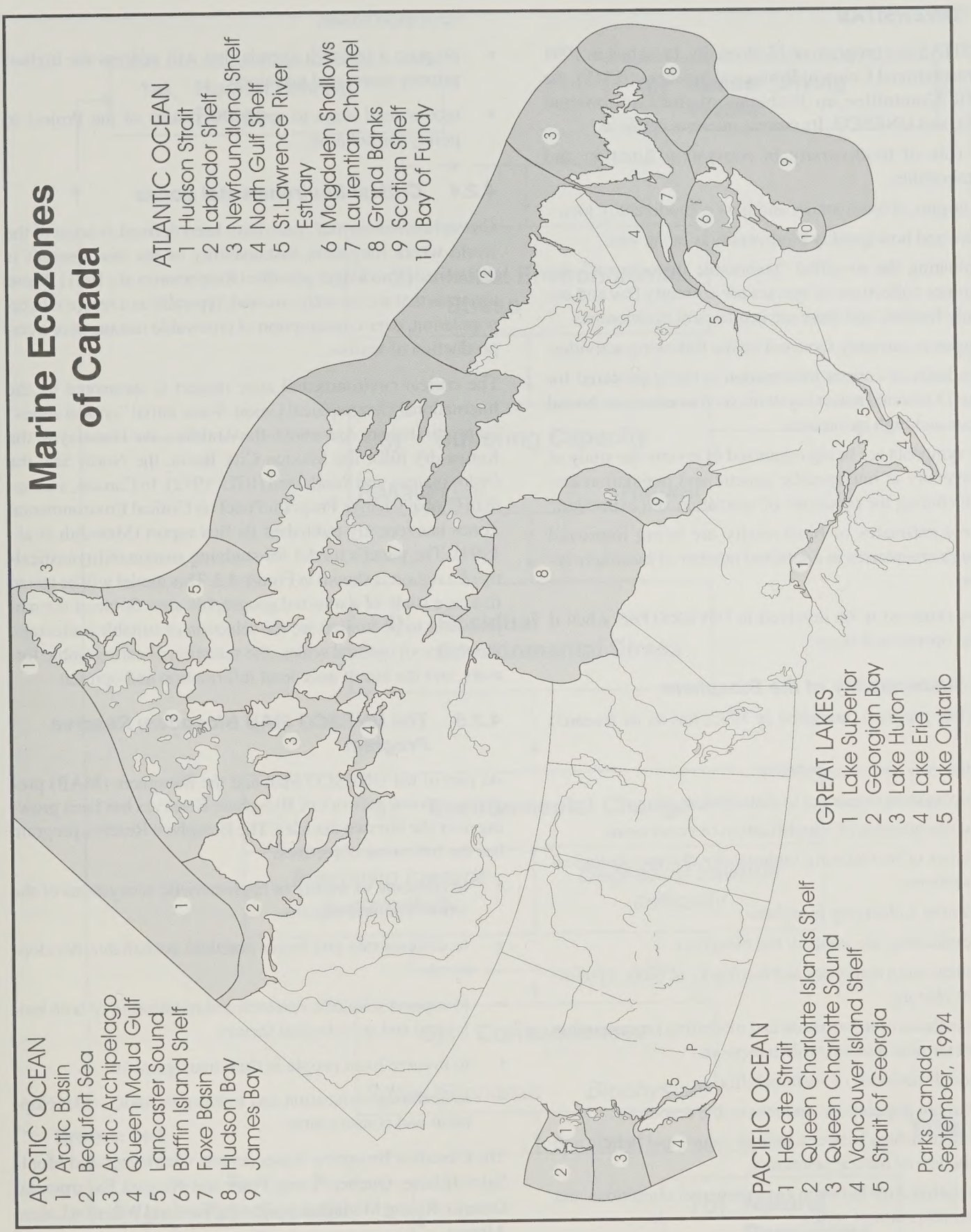


Figure 4.1 Marine Ecozones of Canada (Environment Canada, 1995).

4.2.2 DIVERSITAS

DIVERSITAS is a program on biodiversity, launched in 1991 by the International Union of Biological Sciences (IUBS), the Scientific Committee on Problems of the Environment (SCOPE), and UNESCO. Its current interests relate to:

- the role of biodiversity in ecosystem function and sustainability;
- the origins of biodiversity and how is biodiversity lost;
- where and how quickly biodiversity is being lost;
- eliminating the so-called "taxonomic impediment", i.e. reference collections of species are currently few and unevenly located, and there are insufficient taxonomists.

The program is currently focussed on the following activities:

- a synthesis of current information is being prepared for some 13 selected natural systems such as estuaries, boreal forests and high mountains;
- four symposia are being organized to review the study of biodiversity at intraspecific genetic and population levels, including the processes of speciation and extinction;
- current estimates of biodiversity are being improved through inventories in a selected number of *biosphere reserves*.

Canada is expected to be involved in DIVERSITAS when it reaches an operational stage.

4.2.3 Sustainability of the Biosphere

This SCOPE program, launched in 1992, has as its research priorities:

1. Biodiversity and sustainability
   - ecosystem responses to disturbance
   - consequences of simplification of ecosystems
   - ways of maintaining biologically diverse ecological systems
2. Sustaining a changing biosphere
   - evaluating the status of the biosphere
   - measuring responses and feedbacks of biotic systems to change
   - synthesis of information and modelling processes that determine a sustainable biosphere
3. Human dimensions of sustainability
   - human populations and renewable resources
   - relationships between human values and beliefs and the use of natural resources
   - relationships between environmental conditions and human cultural styles.

The work will be carried out in seven geographic regions, one of which is the North American Great Lakes Drainage Basin. The Project is designed to:

- synthesize the state of knowledge about each of the above ecological issues;
- propose a research agenda that will address the highest priority issues and questions;
- recommend ways to apply the results of the Project to policy formulation.

4.2.4 Critical Environmental Zones

Critical environmental zones have been defined as areas of the world where long-term sustainability of the environment is threatened or no longer possible (Kasperson et al., 1991). These are areas that are severely stressed, typically as a result of overpopulation, over-consumption of renewable resources or overproduction of wastes.

The critical environmental zone project is sponsored by the International Geographical Union. Some initial "critical zones" being studied are Amazonia, the Aral Sea, the Himalayas, the Kenya dry hills, the Mexico City Basin, the North Sea, the Ordos plateau and Sundaland (IGU, 1992). In Canada, a Canadian Global Change Program Panel on Critical Environmental Zones has recently published its first report (Meredith et al., 1994). The panel's model for studying sustainability/criticality of a region is shown in Figure 4.2. This model will be tested in a case study of a selected geographic area. Some of the major issues to be studied are the selection of suitable indicators, the choice of optimal scales, the selection of cartographic formats, and the use of anecdotal information and opinion.

4.2.5 The UNESCO MAB Biosphere Reserve Program

As part of the UNESCO Man and the Biosphere (MAB) program, a global network of Biosphere Reserves has been growing over the last two decades. The Biosphere Reserve program has the following objectives:

- to conserve examples of characteristic ecosystems of the world's natural regions;
- to demonstrate and foster practical sustainable development;
- to support scientific research and monitoring of both biological and sociological factors;
- to involve local people in their management;
- to encourage education and training in resource development and conservation.

The Canadian Biosphere Reserves are: Charlevoix and Mont-Saint-Hilaire, Quebec; Long Point and Niagara Escarpment, Ontario; Riding Mountain, Saskatchewan; and Waterton Lakes, Alberta.

In principle, each Biosphere Reserve should have a strictly protected Core Area, an intermediate Buffer Zone and an outer Transition Area (see Figure 4.3). In practice, there is bound to be worldwide heterogeneity in such an ambitious program.

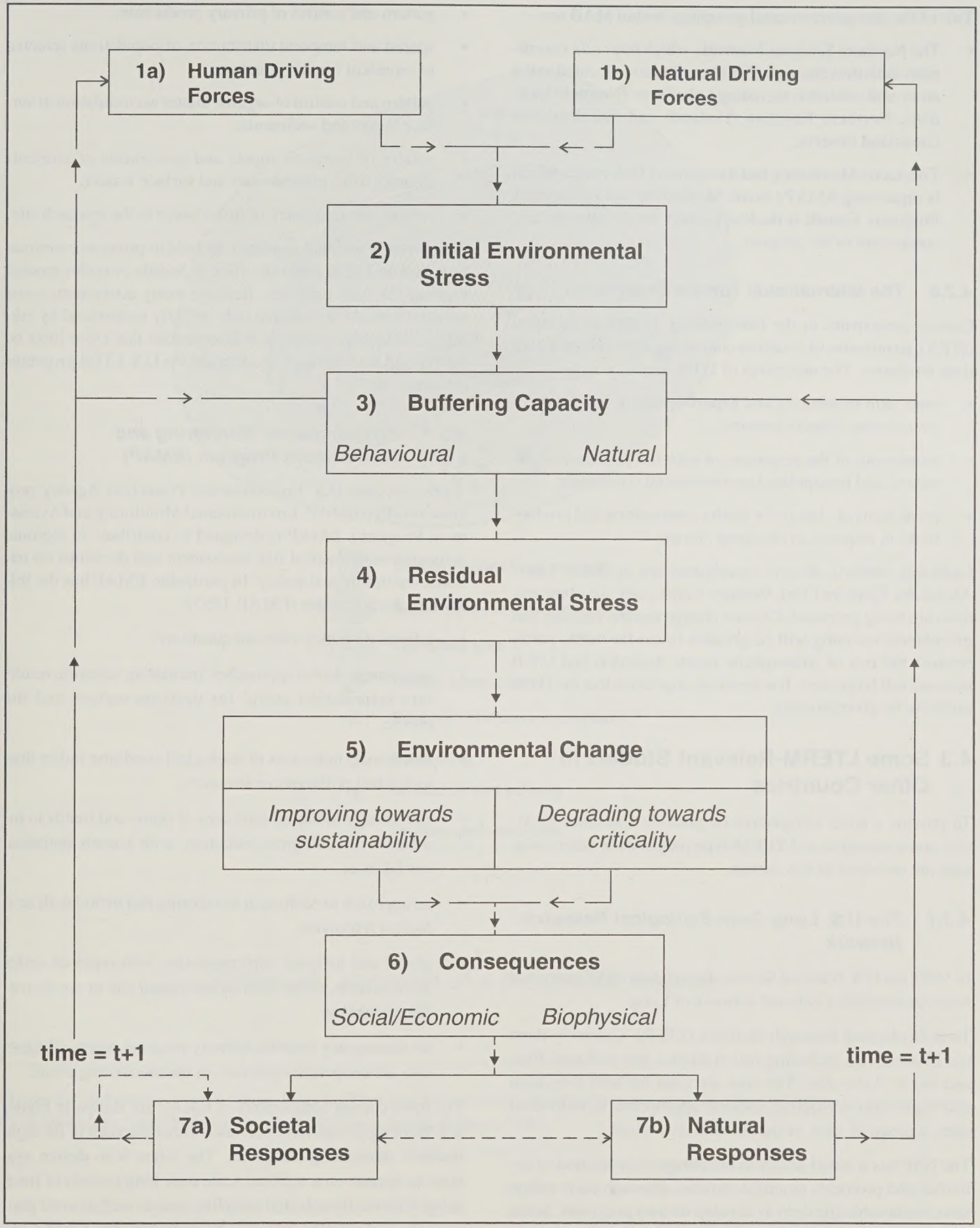


Figure 4.2: Model for studying the sustainability/criticality of a region (Meredith et al., 1994).

Two of the intergovernmental groupings within MAB are:

- The Northern Sciences Network, which *inter alia* coordinates activities amongst Biosphere Reserves located in the arctic and subarctic, including Lake Torne (Northern Sweden), Northern Karelian (Finland) and the Northeast Greenland Reserve.
- The Arctic Monitoring and Assessment Task Force, which is organizing AMAP (Arctic Monitoring and Assessment Program). Canada is the lead country for the atmospheric component of the program.

4.2.6 The International Tundra Experiment

Canada participates in the International Tundra Experiment (ITEX), an initiative of countries containing arctic tundra within their territories. The objectives of ITEX are:

- long-term monitoring and experimentation in relation to year-to-year climate patterns;
- monitoring of the responses of selected plant species to natural and manipulated environmental conditions;
- predictions of changes in tundra composition and productivity in response to changing climate.

Canadian stations already established are at Baker Lake, Alexandra Fjord and Hot Weather Creek, and six other stations are being proposed. Climate change models indicate that greenhouse warming will be greatest in the far north, partly because the risk of stratospheric ozone depletion and UV-B increase will be greatest. It is therefore imperative that the ITEX initiative be given priority.

4.3 Some LTERM-Relevant Studies in Other Countries

To provide a wider perspective on possible Canadian activities, some examples of LTERM-type programs in other countries are reviewed in this section.

4.3.1 The U.S. Long-Term Ecological Research Network

In 1980, the U.S. National Science Foundation (NSF) provided funds to establish a national network of Long-

Term Ecological Research facilities (LTER). Currently there are 18 such sites, including two in Alaska, one in Puerto Rico and one in Antarctica. The sites are used for both long-term and short-term ecological research appropriate to individual sites, a group of sites, or the network as a whole.

The NSF has a stated policy to encourage coordination of activities and protocols amongst stations, although each station has considerable freedom to develop its own programs. Some convergence has been achieved by requiring that five core research areas be included at each site:

- pattern and control of primary production;
- spatial and temporal distribution of populations selected to represent trophic structure;
- pattern and control of organic matter accumulation in surface layers and sediments;
- pattern of inorganic inputs and movements of nutrients through soils, groundwater and surface waters;
- pattern and frequency of disturbance to the research site.

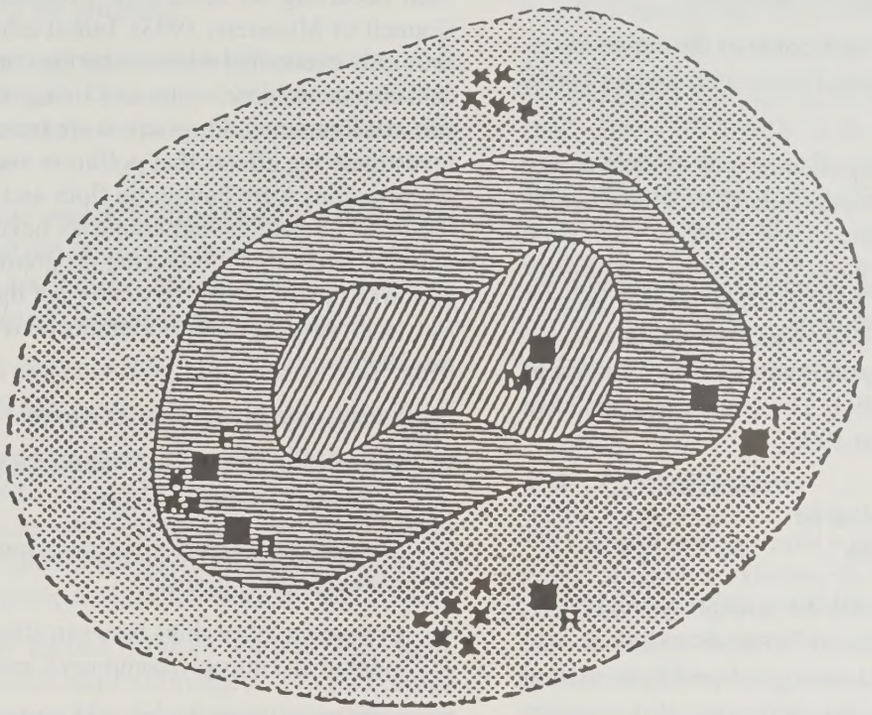
Twice-yearly national meetings are held to promote coordination, and an LTER network office in Seattle provides modest funding for such purposes. Because many ecosystems cross national boundaries and can only be fully understood by taking a continental approach, it is important that close links be established between the Canadian and the U.S. LTER programs (Holling, 1992).

4.3.2 Environmental Monitoring and Assessment Program (EMAP)

A relevant new U.S. Environmental Protection Agency program is called EMAP (Environmental Monitoring and Assessment Program). EMAP is designed to contribute to regional comparative ecological risk assessment and decisions on national environmental policy. In particular, EMAP has the following characteristics (EMAP, 1993):

- a focus on policy-relevant questions;
- assessment-driven approaches, translating scientific results into information useful for decision-makers and the public;
- monitoring indicators of ecological condition rather than individual pollutants or stressors;
- statistically unbiased estimates of status and trends in indicators of ecological condition, with known statistical confidence;
- an approach to ecological monitoring that includes all ecological resources;
- global and national implementation with regional scales of resolution, rather than an individual site or single media orientation;
- an interagency interdisciplinary program where all agencies are cooperative partners in the monitoring effort.

The three current components of EMAP are shown in Figure 4.4. Working groups have been established for each of the eight resource monitoring categories. The intent is to design systems to operate on a regional scale over long periods of time, using statistically-selected sampling sites as well as areal photographs and satellite imagery. In each case, the specific objectives are:



Core area (strictly protected)

Buffer zone (strictly delineated)

Transition area

Human settlements

R Research station or experiment

M Monitoring

E Education and training

T Tourism and recreation

Schematic zonation of a biosphere reserve.

Figure 4.3: Schematic of a Biosphere Reserve. The Core Area is strictly devoted to protection. The Transition Area is not necessarily delimited, but implies involvement of local population (Batisse, 1990).

- to estimate the current status, extent and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence;
- to estimate the distribution and extent of the nation's ecological resources on a regional basis with known confidence;
- to seek associations between selected indicators of nature and anthropogenic stresses and indicators of the condition of ecological resources;
- to provide annual statistical summaries and periodic assessments of ecological resources.

The total EMAP budget was approximately US $37 million in 1993 and US $39 million in 1994. The budget is planned to reach almost US $100 million in 1996.

4.3.3 LTERM-Type Studies in Fenno-Scandinavia

Historically, the impetus for establishing major ecological research and monitoring programs in Fenno-Scandinavia was the realization in the 1960s that ecological problems existed not only in the vicinity of emission sources but also in apparently unpolluted areas far from urban and industrial centres (disappearance of fish from acidified lakes, thinning of birds' eggs, accumulation of mercury in herring in the Baltic, etc.). These problems involved changes that were shown to have been occurring for some time over very large areas (Nordic Council of Ministers, 1993). Initial efforts in the 1970s were primarily concerned with measuring concentrations of chemical substances in air, water and living tissues in rural and marine environments. Programs were broadened in the 1980s to investigate the effects that pollution and other environmental perturbations were having on flora and fauna. More recently, the Fenno-Scandinavian countries have established an international integrated monitoring program to coordinate investigation of the transboundary nature of these problems, particularly with respect to air pollutants (Environmental Data Centre, 1990).

Short-term objectives of the program:

- establish a network of monitoring sites that would use comparable methodologies;
- provide a comprehensive description of within-site and between-site variability;
- evaluate relationships between atmospheric deposition of sulphur and nitrogen compounds and ecosystem responses;
- validate existing models and provide preliminary predictions of ecosystem responses to changes in deposition of sulphur and nitrogen compounds;

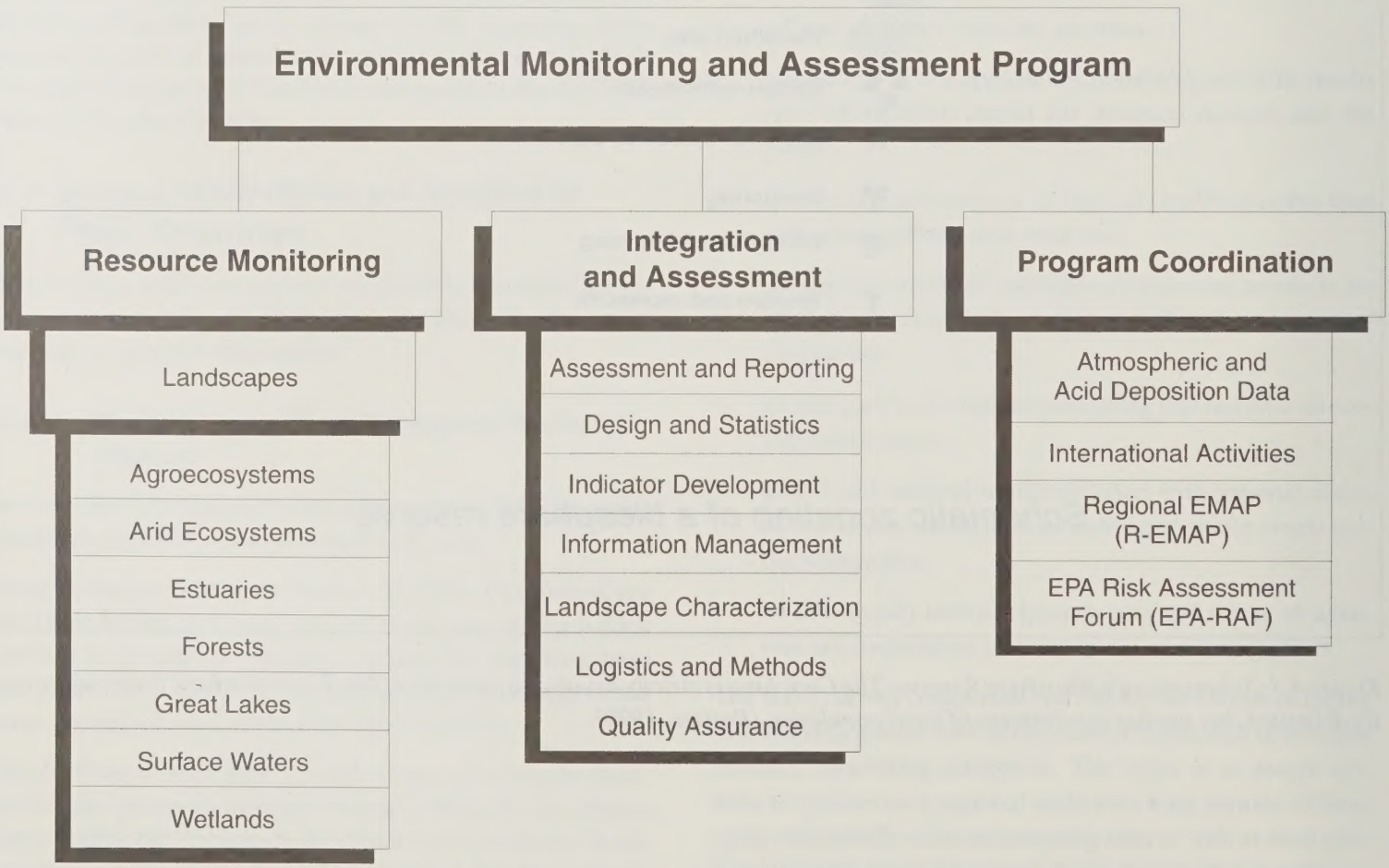


Figure 4.4: The current components of EMAP (EMAP, 1992).

- anticipate future trends and make appropriate recommendations for long-term programs.

Long-term objectives of the program:

- monitor the current and future states of ecosystems, and explain changes in terms of causative environmental factors to provide a scientific basis, such as critical loads, for emission controls;
- develop and validate models for the simulation of ecosystem responses, and use them in concert with survey data to make regional assessments and to estimate responses for actual or predicted changes in pollutant stress.

Some special problems that have been identified by the Fenno-Scandinavian countries are:

- The most challenging problems in monitoring are institutional. Improvements are needed in coordinating mechanisms between the agencies involved, in problem framing to ensure that the right questions are asked, in information management and particularly in how information is used;
- Better linkages are needed between research and monitoring programs within national budgets. As a problem is identified, agencies are always asked to undertake more research, or more monitoring, or both, but often within existing resources;
- Monitoring programs deal with problems often related to human lifestyle issues. As a result they are inherently political. When LTERM results are used as a policy tool, the scientists involved must recognize that science used for policy is extremely value-laden and plagued by uncertainties that must be managed effectively.

4.3.4 Serengeti: An African Example

The Serengeti ecosystem in Tanzania is unique in both the size of the migratory herds of ungulates and the diversity of mammals and birds. This is the last remaining undisturbed large mammal migratory system in Africa, covering 25,000 km^2 in the Serengeti, plus an additional 25,000 km^2 of surrounding land, where there is significant human influence. The LTERM program began in 1962 and is ongoing (Sinclair and Norton Griffiths, 1979; Sinclair and Arcese, 1995a).

Monitoring is concentrated on soils, grasslands, woodlands, herbivore populations and their reproduction and mortality, and predator populations. Information is also collected on climate variability and human disturbances. Serengeti was the first study in which integrated use was made of satellite, aircraft and ground-truth measurements to monitor animal populations.

The current research focus is directed towards answering the following questions (Sinclair, 1995):

- Population dynamics (e.g. preservation of particular endangered species or habitats);
- Establishment of priorities in conservation biology (e.g. what is the basis for selecting a particular species or habitat?);
- Will species and their associated communities and habitats be conserved by preserving land?

For Serengeti, the answer to the third question seems to be "no". Since 1910, 40% of the natural ecosystem within the park boundary has been lost; the rhinoceros has been eliminated, and the elephant population has been reduced by 80%. Some 40% of the natural ecosystem has been lost, and there is an indication that the loss rate is accelerating (Sinclair and Arcese, 1995b). The Serengeti provides a lesson in the necessity to study and manage a park or biosphere reserve as a combined ecological/socioeconomic system, i.e. the UNESCO MAB approach.

4.4 Conclusion

This chapter has surveyed some of the LTERM-relevant programs already in existence in Canada, the U.S., and in other countries. One lesson that can be drawn from this brief overview is that a continent-wide perspective would be necessary in order to ensure the success of an LTERM program in Canada because of ecological interdependency of the two countries.

Recommendation (4.9): It is recommended that the Canadian LTERM program maintain both a continental and a hemispheric perspective. Close liaison should be developed between the Canadian LTERM and various relevant U.S. hemispheric national and state programs, and also circumpolar research studies. In the case of marine LTERM programs, the spatial scales involved must be sufficiently large to correspond to those that include the life cycles of the species involved.

The Serengeti example demonstrated that even in relatively protected areas, long-term changes can take place in wildlife populations. This agrees with computer simulation models that predict global change over the next century will be unprecedented (see Chapter 3).

Recommendation (4.10): It is recommended that the Canadian LTERM program maintain a long-term (50 years or longer) perspective. Accepting the precautionary principle and assuming that ecological changes will indeed occur, considerable effort should be given to developing early warning indicators and improving our understanding of ecosystem functioning under changing conditions.

The broad range of programs and experiences surveyed could provide an invaluable basis on which to builda Canadian LTERM program. Such a program, in turn, could serve to help coordinate currently disparate efforts in the field, both in Canada and on the international stage. As a condition of building an efficient, cost-effective national program, periodic assessments of existing and emerging programs need to be carried out — only in this way can available resources be put to the best possible use.

Chapter 5
A Proposed Canadian LTERM Program

In the preceding chapters, this report has argued for the urgent need for a Canadian LTERM program. We have also surveyed existing programs that could serve as models or building blocks. Noting that the 21st century may be a period of unprecedented socioeconomic and environmental changes, we reiterate the main recommendation of this report:

Recommendation (1.1): Noting that the 21st century may be a period of unprecedented socioeconomic and environmental changes, it is recommended that a national Canadian LTERM program should be given the highest priority. This program would include a network of LTERM sites which would be established across Canada, building on existing facilities and programs.

In this chapter, we set out the basic principles and general objectives for a Canadian LTERM program and discuss the practical problems that must be overcome in achieving these objectives. In doing so, we take the opportunity to integrate many of the observations and recommendations made earlier in the report.

5.1 Principles of a Canadian LTERM Program

5.1.1. An Ecosystem Approach

An ecosystem approach should be taken to the design of a Canadian LTERM program. Ecosystems behave as a connected whole and must be studied as such. An ecosystem's behaviour cannot be understood solely by decomposing it into pieces, because individual behaviour cannot be summed to give the behaviour of the whole (system).

Ecosystems must also be analyzed from a hierarchical perspective, i.e. one that is understood in the context of the larger systems to which they belong, and in terms of their component parts.

One useful conceptual framework for understanding ecosystem functioning and-stress-response dynamics is as self-organizing thermodynamic systems which are constantly responding to changing environmental conditions in the context of the energy, materials and information available to them. The notion of an ecosystem in a steady state is often an illusion; ecosystems are continually undergoing a birth-growth-maturity-death process (See Fig. 2.2). Ecosystems can only be understood in the context of these processes with particular attention to their temporal and spatial scales.

Recommendation (5.1): An ecosystem approach must be taken in the LTERM program. Ecosystems should be studied inter alia as non-linear systems with multiple states between which the system may flip.

5.1.2 Space and Time Scales

Canada is a very large country with many different climatic and ecological zones. This means that considerable care should be taken in the selection of the most appropriate time and space scales in the design of a Canadian LTERM program.

A long-term perspective on ecosystem behaviour is essential. Many relevant trends are only detectable ona long-term basis or may involve significant time lags between environmental change and ecosystem response. And because ecological systems often cycle over many decades, the time scales of interest in a Canadian LTERM program extend from decades to centuries.

Recommendation (5.2): Ecosystems need to be studied on a variety of temporal scales, from decades to centuries.

A Canadian LTERM program must also recognize the wide range of spatial scales that are involved — from regional to continental to global. This is due in part to both east-west and north-south differences in geophysiology and climate.

Recommendation (2.3): The Canadian LTERM program should seek close working relations with the paleoecology and remote sensing communities in Canada. In both cases, the human resources and technical support already available will be invaluable.

The patchiness of ecosystems results in an important difference in strategies for monitoring ecological and geophysical systems. Meteorologists, for example, select "representative" observing sites (small fenced grassy plots) that minimize spatial variability on the very local scale. Then using a network of sites 300 km apart, the large-scale weather patterns can be determined. For ecologists, on the other hand, small-scale patchiness contributes to the integrity of the systems being studied, and must be factored into models and sampling strategies.

Ecosystem patchiness occurs at all scales but is least studied at the landscape scale, where fragmentation of habitat can endanger the reproductive success and survivability of animal and plant populations. Especially in the context of biodiversity, the long-term maintenance of ecological corridors is critical, which means that habitat destruction and fragmentation should be monitored over the long term.

Recommendation (5.3): In studying ecosystems, efforts should be made to capture the effect of ecosystem patchiness on a variety of scales.

This means that LTERM sites must be rather large, at least a few hectares. Wherever possible, an LTERM site should encompass a small catchment, providing basic information on hydrological biogeochemical cycling (SCOPE, 1994).

Recommendation (5.4): Each terrestrial LTERM site should preferably include within its bounds, a small calibrated catchment, providing basic information on hydrological and biogeochemical cycling.

It will be important to exploit the research opportunities that ecotones provide. Ecosystem response to climate change is often amplified at the boundary between vegetational complexes such as the boreal/cool temperate forest boundary. A Canadian LTERM program should therefore include transects across large-scale boundaries — from the landscape scale upward to the continental scale. Wildlife, birds, insects, seeds, pollen, spores and other biological material move freely across the Canada United States boundary so that a continental-scale approach to ecological research and monitoring is also clearly desirable.

Recommendation (4.10): It is recommended that the Canadian LTERM program maintain a long-term (50 years or longer) perspective. Accepting the precautionary principle and assuming thatecological changes will indeed occur, considerable effort should be given to developing early warning indicators and improving our understanding of ecosystem functioning under changing conditions.

Continental and global-scale Canadian LTERM programs should be integrated into relevant international efforts. In particular, the overall objectives of the Canadian LTERM program should be compatible with, and should contribute to, those of IGBP/GCTE. In addition, the Canadian LTERM stations should be linked to international networks, e.g. to UNESCO/MAB and the InterAmerican Grid (IAI). Other examples of Canadian efforts that could contribute internationally include NBIOME and ITEX.

Recommendation (4.8): Canada contains a significant fraction of the Earth's land and water surface. Thus Canadian participation in international terrestrial and marine ecological programs, particularly IGBP/GCTE, should be given high priority.

5.1.3 Stressed and Already Degraded Ecosystems

Special attention should be given to stressed and already degraded ecosystems, using some of the new ideas relating to ecological integrity and sustainability, including the concept of sustainable development of regional ecosystems (Regier and Baskerville, 1986). For such systems, the additional stresses imposed by global environmental change in the 21st century may trigger irreversible effects in some cases. Particular emphasis needs to be placed on the development of indicators of ecological integrity.

Recommendation (5.5): Special attention needs to be given within LTERM to stressed and already degraded ecosystems, within the context of ecological integrity and sustainability.

5.1.4 Program Continuity

The spatial and temporal scales implied by a national LTERM program raises important institutional issues, such as the continuity of financial support and the long-term commitment of facilities. In the past, ecological research and monitoring sites have seen their programs interrupted in favour of other, unrelated uses. For example, the Marmot Creek International Hydrological Decade site in the Kananaskis Valley of Alberta was lost to the Calgary winter Olympic Games.

Recommendation (5.6): A main recommendation of the Panel is that long-term institutional and financial support be provided by the government of Canada, in collaboration with the provinces and the community of Canadian ecologists, for an LTERM Program.

Recommendation (5.7): Because of the importance of Canada's renewable resource base, it would probably be desirable to ensure that an LTERM Program be supported at senior levels of the Federal and Provincial governments (i.e. Cabinet level).

There is no institution in Canada that has a comprehensive environmental mandate or the permanency of resources to undertake an LTERM program on its own. LTERM in Canada needs a champion agency, beyond the policy level and into the program management level, including information management, coordination, and reporting, i.e. an environmental Statistics Canada.

Recommendation (5.8): The federal government should situate responsibility for a Canadian LTERMprogram in a single national agency, whether that agency be pre-existing or created for this purpose.

Given the existing climate of government restraint, all programs are vulnerable to funding reductions. It is crucial, however, that the value of existing long-term research and monitoring programs be recognized.

Recommendation (5.9): In any cost-cutting exercise, the Panel urges LTERM sponsors to accord the greatest possible protection to on-going, long-standing programs. In return, LTERM operators must accept the responsibility to maintain high levels of ecological relevance, to maintain standard methods, and to report to their peers and the public at large.

5.1.5 A Variety of Perspectives

Each ecosystem should be studied from as many perspectives

as possible, including the following:

- hydrologic cycling (catchment areas should be selected wherever possible);
- biogeochemical cycling of carbon and other substances through the ecosystem;
- food webs;
- overall energetics;
- geomorphology and soils;
- population dynamics (competition, predator-prey relations, habitat, biodiversity);
- life-cycle assessments, e.g. of toxic substances;
- the effects of landscape patchiness, including corridors, on ecosystem processes;
- stress-response assessments;
- ecosystem integrity, i.e. as a non-equilibrium self-organizing system.

Most importantly, these perspectives should be applied in an integrated fashion rather than separately as is frequently done. For example, population dynamics and biogeochemical cycling are rarely investigated in the same watershed in the same year.

Recommendation (5.10): Ecosystems should be studied from as many perspectives as possible, including hydrological cycling, biogeochemical cycling, food webs, overall energetics, geomorphology, and soils, population dynamics, life cycle assessments, landscape patchiness and corridors,-stress-response assessments and ecosystem integrity.

The social sciences can also help shed light on the causes of long-term ecological change. Thus, relevant socioeconomic factors — such as land use change and human population growth patterns — should be included in LTERM models and monitoring programs.

Recommendation (3.1): The Canadian LTERM program should use a strong socioeconomic component, whose goal is to permit an integrated approach to investigations of the socioeconomic causes and consequences of long-term ecological change.

5.2 Objectives of a Canadian LTERM Program

1) Objective: Understanding and Monitoring Ecosystem Change

   - To improve understanding of how natural ecosystems work, i.e. to understand ecosystem processes and linkages of processes between different spatial (patch to region) and temporal scales;
   - To identify key indicators;
   - To explore ecosystem behaviour under conditions of global change.

   Related monitoring objectives:

   - to monitor ecosystem integrity (see Box 5.1);
   - to provide data for hypothesis testing;
   - to provide baseline data on the basis of which key parameters could be established to be measured at reference sites;
   - to provide information for developing policies for sustainable resource planning;
   - to assess the effects of human activities on Canada's ecosystems.

Box 5.1
Monitoring Ecosystem Integrity (Woodley and Theberge, 1992)

Hierarchical Scale	Monitoring Measure
Individual	• growth and reproduction rates of indicator species
Population	• minimum viable population size • populations dynamics of selected species
Community	• species diversity • succession/retrogression nutrient cycling
Landscape	• climate • primary productivity/respiration • minimum viable area • habitat fragmentation

2) Objective: Early Warning of Ecosystem Change

   - To provide early warning of long-term changes in ecosystems.

   Related monitoring objectives

   - selection of appropriate early-warning indicators;
   - evaluation of non-equilibrium/non-linear models as appropriate conceptual frameworks for assessing early warning indicators.

3) Objective: Ecosystem Response to Disturbances

   - To use natural disturbances such as forest fires, blowdowns, insect infestations, and anthropogenic disturbances such as habitat destruction and fragmentation, to examine ecosystem responses to perturbation.

   Related monitoring objectives:

   - to assess the effects of fire suppression on ecosystem function;

- to determine the extent to which anthropogenic interferences such as spraying affect insect populations and cycles;
- to assess changes in extent and frequency of blowdowns which may be an indicator of forest stress;
- to track the effects of natural disturbances on forest functions such as carbon storage.

4) Objective: Ecosystem Experimentation

- To undertake long-term controlled experiments, with respect to harvesting methods, manipulation of succession, etc.

Related monitoring objectives:

- dependent on nature of controlled experiments.

5) Other Objectives:

- To supply information for use by the media and NGOs interested in environmental quality and trends;
- To provide ground-truth for remote sensing of ecosystems;
- To provide baseline data for environmental impact assessments prior to proposed development;
- To support international programs such as IGBP and DIVERSITAS.

Recommendation (5.11): The objectives for LTERM programs should be carefully specified for each station. These objectives need not be the same across all stations in the national network.

5.3 Meeting the Objectives: Some Practical Considerations

5.3.1 LTERM Sites and Stations

Site selection

Canada should identify and set aside a set of long-term protected regional sites in which to locate LTERM facilities. Such sites should be located in both undisturbed and built-up areas of the country. This will require political support from the Canadian Council of Ministers of the Environment so that jurisdictions will act quickly and together to set aside or zone appropriate sites. Some practical advice on the selection of specific sites is given in Box 5.2.

Build on existing programs

LTERM sites should be selected so that they complement existing relevant programs, where infrastructures are already in place (e.g. national and provincial parks, research forests, university and government field stations).

Box 5.2

Operations Rules for Selecting An LTERM Site (Heal et al., 1993)

Mandatory: A site must satisfy the following:

- the operating agency managing the site must have tenure for monitoring for at least the next 50 years;
- the operating agency must be able to provide the core set of monitoring variables, to the necessary quality standards, plus the core set within one or more of the following foci:
  - biodiversity and ecosystem composition change
  - change in agricultural performance
  - change in ecological function
  - change in landscape pattern and use

Preferred: These rules are for prioritizing sites that satisfy the above criteria:

- supported sites should have preference over the new sites;
- sites having a set of environmental characteristics (including climate, soil types, land use types and biotic richness) not already represented in the network will be preferred over sites already represented;
- committed institutional support at the local level, or LTERM program important to national resource management or development needs;
- location in a priority region of one of the participating sponsors;
- practical and economical to operate.

Site continuity

Tight economic times mean that not all LTERM activities can be continuously operated. However, Canadian land management agencies should protect existing LTERM sites so as to safeguard the ability to resuscitate programs in the future.

Site management

While controlled experiments are vital to research of all kinds, long-term monitoring of natural, benchmark sites is only possible if those sites are shielded from undue disturbance, not only by other land uses but by manipulative research. Researchers and site managers should jointly develop protocols laying out the thresholds of disturbance to be tolerated such that long-term baseline comparisons remain possible. Of course, there is need to study stressed systems, such as urban or waterfront systems.

Recommendation (5.12): Site continuity should be ensured for existing sites and shielded from undue disturbances.

5.3.2 Key Research Considerations

Selection of leading indicators

Of whole ecosystems

There is need for an agreed set of whole-system leading indicators of key ecological components for a series of benchmark ecosystems. One suitable approach is based on the recognition of driving forces and rapidly adjusting responses (mutation, population size, migration, etc.), basically a stress/exposure/response model. In this context, measurement of the overall energy balance of the ecosystems using remote sensing, nutrient rates and indicators of the health of populations, is necessary. The indicators themselves should preferably be easily and reliably measurable, i.e. they should be simple parameters, whether they reflect simple or composite phenomena.

Of landscapes

There is need for an agreed set of leading indicators of landscapes. These might include *connectivity* (a measure of migration routes), *dominance* (a measure of the extent to which a few patch types dominate the landscape), *contagion* (a measure of the extent to which patch types are clumped) and *fractal dimension* (a measure of patch sizes) (Riitters et al., 1992).

Composite indicators

As well as single leading indicators, society needs composite indicators to aid in public, political and institutional understanding and in warning of environmental trends and threats. Composite climate measures (e.g. frost-free days that reflect several phenomena — temperature, cloud, radiation) are examples. A surrogate or complementary set of measures could come from inexpensive satellite data.

Natural versus induced changes

There is a need to distinguish human-induced changes from natural changes, particularly where both sets of stresses bear upon the same phenomenon or parameter. At the stress level, this is measurable. At the response level, this may require modelling to help understand the various stresses and responses. In order to build an appropriate knowledge base, we must continue, and indeed increase, large-scale, integrated research projects, like BOREAS, that examine biosphere-geosphere-atmosphere-hydrosphere links, especially chemical and energy transfers between natural systems, their vectors, linkages and feedbacks.

Scaling up

Particularly for meso- and macro-scale models, there is often a need to "scale up" (or extrapolate) from local to regional conditions. In the case of the Experimental Lakes Area, for example, the Northwest Ontario Lake Size Series (NOLSS) program seeks to scale up the hydrological and limnological properties of small lakes to lakes of the size of Nipigon and Superior. See figure 5.1 (Fee and Hecky, 1992). This could be important in many LTERM programs.

Recommendation (5.13): Considerable effort should be given to improved understanding of ecosystem functioning under changed conditions, and of the potential for extrapolating findings to larger scale phenomenon.

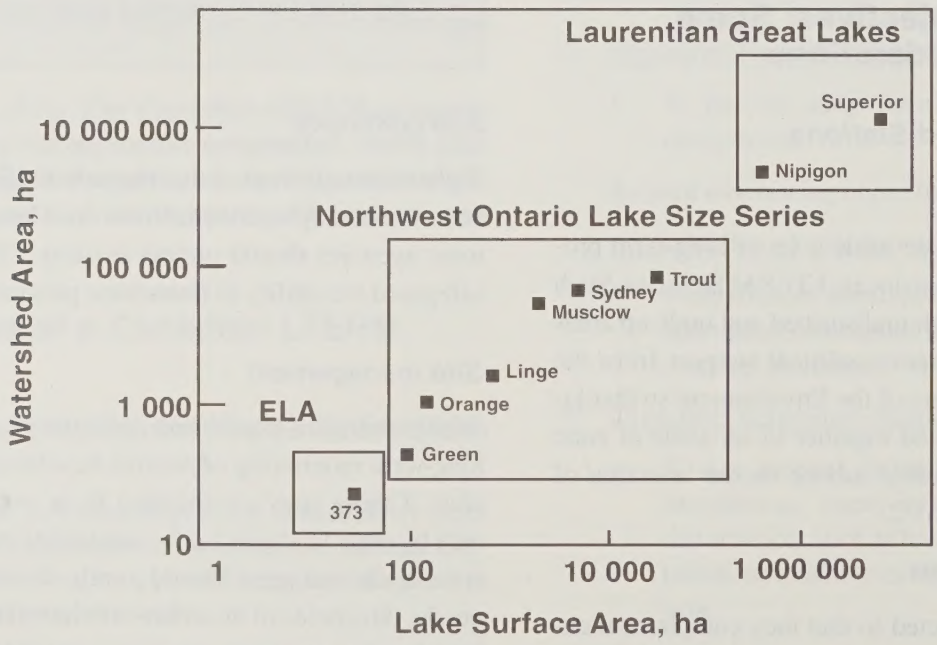


Figure 5.1 NOLSS (Northwest Ontario Lake Size Series) experimental design. The NOLSS lakes fill the gap that separates ELA lakes from the Laurentian Great Lake (Fee and Hecky, 1992).

5.3.3 Collecting and Managing Data

Evolution of instrumentation and scientific understanding

New measurement methods may render current techniques obsolete. Great attention must be paid to calibrating the new against the old technologies in such cases. Whenever possible, overlapping sets of data should be collected for a time. Furthermore, scientific advances may make the original question or hypothesis uninteresting, and justification for continuing the LTERM facility may seem to disappear. Experience shows, however, that both the data and the facility will often become invaluable for other (often surprising) reasons.

Citizen monitoring

Given the magnitude of the LTERM task, the value of volunteers must be recognized in assisting with extensive and repetitive observations (Stokes et al., 1990). At the same time, LTERM managers must be aware of the need to ensure the quality of data collected by citizens or by students. This will only be possible if citizen monitoring is geared to simple and attractive indicators that can be collected reliably by a large number of volunteers, and that can be coupled to data from selected benchmark sites. Bird and insect surveys, plant checklists, volunteer climatological observers and shore erosion stations are examples.

Sample repositories

Given that we don't always know what to measure now for the problems of 100 years hence, we need to safeguard existing and establish more sample banks for retrospective analysis. Some banks already exist for individual disciplines (DNA repositories, ice and sediment cores, plant tissues) but the program needs to be systematized for a wide variety of substances: air, water, sediment, pollen, plant and animal tissues, whole specimens, and so on.

Data Management Strategy

Long-term implies that programs are designed to run for decades. Ultimately therefore, the original investigators will no longer be involved in the program, and *metadata* (descriptions of data banks) become essential. Metadata must pass the 20-year test, i.e. an investigator twenty years hence must be able to understand the historical data bank solely on the metadata archived with the data. Some of the properties of metadata are given in Box 5.3.

There is also a need for ecological data systems to be consistent across Canada, and in some cases, with data collected in international programs. This is one of the reasons why the development of a national data management strategy is so important. Some of the factors to be considered in the development of such a national strategy are:

Box 5.3
Some Desirable Properties of Metadata (CGD, 1991)

- identification of contributors to data sets
- background information
- scope and purpose of the program
- data collection procedures
- station history
- description of instrumentation
- definitions of calibrations
- definitions of variables
- quality assurances
- limitations of data
- systematic and random errors
- input/output data routines
- references

- Scientists and data managers should be jointly involved in the design of data systems.
- Serious thought should be given to the relative advantages of adapting existing systems to designing totally new ones. The former is easier to implement but it may not stand the test of time.
- The system selected should provide information analysis services for various classes of users.
- Data directories should be compatible nationally.
- Data management research should be encouraged.
- About 10-15% of the budget for a large monitoring program should be spent on quality control, data storage and documentation (NAS, 1994).

Recommendation(5.14): The Canadian LTERM program must establish a national data management strategy, including the development of a metadata system. This strategy should map out means for keeping up with evolving instrumentation and scientific understanding, the use of citizen monitoring programs, and the design of repositories for biological samples and data archives. About 10-15% of the LTERM budget should be spent on quality control, data storage and documentation.

5.4 Network Analysis

Longer time scales imply larger spatial scales, and some of the ecological issues that will develop in the next fifty years will require national and, in some cases, global approaches. This will be facilitated by strengthening research and monitoring activities directed to those aspects common to any/all ecosystems e.g. self-organization, nutrient cycling, biomass, and biodiversity. The benefits of comparable monitoring programs

and research approaches across Canada will be enormous.

Because of climatological, limnological and geological variability across Canada and around the world, the biosphere is not homogeneous. If networks are to be effective, LTERM sites should be selected carefully. The basic factors to be considered are (Sokolov and Puzachenko, 1985):

- high sensitivity to global influences, combined with low sensitivity to local effects, thus providing early indicators of global change;
- high specificity to stress-producing factors, e.g. ozone damage: thus promoting identification of factors causing the changes;
- representativeness with respect to larger areas, i.e. away from ecotones, thus providing the possibility of extending the observational results to surrounding areas (Kotlyakov et al., 1988).

In some cases, of course high sensitivity to local effects may be desirable. Some "hot spots" might provide the very first indications of emerging regional problems.

Some ways in which data from a network of LTERM facilities can be used are:

- for studying spatial gradients of sulphate deposition, tropospheric ozone concentrations, tree-ring widths, methane production, density of small mammal populations, etc.;
- for comparing nutrient cycling, biomass production, food webs, biodiversity, etc. under differing geophysical regimes;
- for obtaining early warnings of biological invasions, the spread of species diebacks, emerge of "new" pests and diseases, etc.

Networks will be most effective if an overall strategy is in place with respect to the long-term objectives to be met by the network, superimposed on the objectives established for individual LTERM sites. Box 5.4 suggest some general principles in the design of LTERM networks.

Hicks and Brydges (1994) have recently suggested the idea of "nested networks" as a unifying strategy for environmental monitoring and assessment. The underlying concept is that of tiers of stations, each tier being composed of sites selected for specific purposes (usually involving only one or a very few disciplines) but arranged to maximize the number of common sites where questions involving a wide range of disciplines can be addressed.

Remote sensing could be an important integrating mechanism for LTERM networks. For example, *gap analysis*, which is of considerable significance with respect to biodiversity studies, is greatly facilitated through the use of satellite photography (Estes et al., 1992; Newmark, 1983). A second example is a continental vegetation classification scheme based on the structural characteristics of plant canopies as observed from space (Running et al., 1994). The three attributes that can be readily observed in this way are: permanence of above-ground live biomass, leaf longevity, and leaf type. Paleoecology could also help integrate finding from an LTERM network by allowing researchers to interpret current changes in the context of very long-term ecosystem evolution. Expertise in these fields is already established in Canada and could serve as an invaluable resource to an LTERM program.

Box 5.4

Some General Principles for the Design of Long-term Monitoring Networks (After Heal et al., 1993)

1. Establish initial conceptual models.
2. Build around scientists with common interests (but not exclude alternative viewpoints).
3. Identify short-term as well as long-term goals.
4. Capitalize on well-studied sites and past data.
5. Design should be simple, flexible and adaptable.
6. Design for extrapolation to scales of 100x100 km.
7. Plan for detection of rare or unique events.
8. Include experiments, and both managed and unmanaged systems.
9. Sample transition as well as median conditions.
10. Include both intensive and extensive sites.
11. Archive samples as well as data for future analyses.
12. Quality assurance must be built into the program.

The Panel considered the important question: what is the optimal number of LTERM stations/facilities that should be established across Canada? Unfortunately, there is no simple answer to this question. There are many reasons for establishing ecological monitoring stations, and networks of such stations. For Environment Canada's State-of-Environment Reporting, for example. However, there are many other reasons for establishing LTERM Stations, as mentioned in Sections 1.2, 5.1, 5.2 and here in 5.4. Looking ahead 50 years, it is not possible to provide firm list of candidate ecological questions that may require LTERM data. Even if such a list could be drawn up, the optimum number of LTERM stations would also depend on the spatial gradients involved, the natural variability (patchiness) of the ecosystems involved, and the accuracy required to answer the questions posed. Under the circumstances, therefore, the advice of Hicks and Brydges (1994) mentioned above is about the best that can be offered i.e. the national LTERM authority should establish tiers of stations, each tier being designed for specific purposes, but with overlapping monitoring programs wherever possible. This approach should be

supplemented with remotely sensed data from satellites to provide spacial coverage. Even if remotely sensed data of a particular kind are not of immediate value, the data should be archived for later analyses (perhaps decades later).

Recommendation (5.15): Individual Canadian LTERM facilities should be integrated into a national network. Networking among researchers and administrators should be encouraged and facilitated through electronic mail, regular meetings of station managers and research scientists, and the above-mentioned data management strategy. [In some cases, of course, networking has been detrimental by adding bureaucracy. This tendency should be avoided.]

Recommendation (5.16): Noting that networks of LTERM stations will be required to assess a wide range of public issues and research questions, some of which cannot yet be imagined, the principle of "nested networks" should be followed, in which tiers of stations are established, each to be activated as required. These networks should be supplemented by archived remotely sensed ecological data covering the areas between stations.

5.5 Some Questions To Be Asked When Establishing an LTERM Facility

Three questions should be asked when establishing an LTERM facility:

- Can a core measurement program be designed that will meet the needs of a variety of present and future users? The core measurements should depict the material flows, energy flows and biodiversity as well as the primary components (air, water, soil and biota) that make up an ecosystem. The core measurements serve as a basis for other investigations into ecosystem function. While there is always the possibility that some component may be overlooked or deemed "missing" from the initial program, the likelihood is reduced if the study design has been carefully formulated and is hierarchical, i.e. sub-programs are devised within a layering of space and time scales.
- Can the LTERM facility meet multiple objectives? This is a difficult question to answer, requiring case-by-case assessment. For some applications, sites need not be located in homogeneous terrain. For example, in order to measure the surface fluxes of CO_2 using an aircraft, a uniform vegetative cover over flat terrain would be essential. In other cases, however, several sites in a terrain crossing an ecotone, or inland from a coast, would be desirable.
- Are there LTERM problems for which a single site or a network of sites is inappropriate? Unfortunately, this is sometimes the case. For example, the limited size of LTERM sites is sometimes a crucial deficiency, e.g. in biodiversity studies, where habitat fragmentation may lead to non-representative results.

Recommendation (5.17): In choosing sites, attention should be given to the kinds of questions that each site will be capable of answering, and not answering.

5.6 Relation Between This Panel's Recommendations and Environment Canada's Program on LTERM

As discussed in Section 4.1.3, Environment Canada is establishing a national LTERM program built around Ecological Science Centres, one for each of Canada's 15 ecozones. Focussing on sustainable development, the main goals of this program are to provide periodic reports on the state of the Canadian environment, and to permit environmental forecasting. Ecological research and monitoring are key components of the program.

This Panel endorses the efforts of Environment Canada to establish a national LTERM program. In particular, the network of Ecological Science Centres could support the program proposed in this report, as well as those being elaborated within SOER. There are, in fact, many common elements in the two sets of proposals. The main difference is that the orientation of this Panel is clearly towards activities relating to IGBP and other international programs, designed primarily to increase understanding of long-term ecosystem functioning, particularly with respect to the responses of Canadian ecosystems to global change over the next century, and to provide early warnings of such changes. Complementing the efforts now under way at Environment Canada with the proposals of this Panel would lead to improved strategies for long-term management of Canada's natural resources.

Chapter 6
Implementation

The LTERM Panel, appointed by the CGCP of the Royal Society of Canada, has established what it believes to be an appropriate framework for an LTERM Program in Canada. It has also stressed the urgency of the concerted effort of all those involved in LTERM activities in Canada to ensure that the Program is built on the very considerable existing initiatives and facilities. The Panel would like to conclude this report with three recommendations which would provide guidance for implementation of its proposal. They would also ensure that appropriate mechanisms are in place to monitor the progress of the LTERM Program and, if necessary, to modify it.

The Panel recommends that Environment Canada be invited to act as the lead agency for the LTERM Program in Canada.

Recommendation (6.1): It is recommended that Environment Canada (EC) be officially recognized as the LTERM lead agency in Canada. This recognition must be backed by a commitment for long-term funding of LTERM activities in Canada and should include specific reference to the necessary reporting and advisory mechanisms that will ensure that EC plays its role of lead agency.

The Panel believes that the LTERM Program champion should receive advice from a group of scientists, representing the LTERM community in Canada and having the necessary expertise to formulate recommendations regarding changes to the Canadian LTERM program or new initiatives. It would also ensure that the Canadian Program would remain responsive to national needs as well as to international initiatives. A standing LTERM Committee of the CGCP (with members from the Canadian Climate Program Board, the Canadian Federation of Biological Societies, university researchers, and scientists from federal and provincial departments), operating at arm's length from governments, could play such a role.

Recommendation (6.2): It is recommended that the Canadian Global Change Program appoint an LTERM Standing Committee that would receive reports from and provide advice to EC and other organizations involved in LTERM activities in Canada. The costs associated with the operation of this Committee would have to be covered by EC, other government departments, provincial ministries and other bodies supporting the Program.

The Panel also believes that a report describing LTERM activities in Canada and making recommendations should be prepared . The Standing LTERM Committee could prepare such a report, which could be a credible source of information for EC and other sponsoring bodies.

Recommendation (6.3): It is recommended that a report presenting the State of LTERM activities in Canada be prepared regularly by the proposed Standing LTERM Committee.

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Appendix A
Glossary

ABIOTIC refers to non-living characteristics of the environment, i.e. the physical and chemical components.

BIODIVERSITY is the variety and variability among living organisms and the ecosystems in which they occur.

BIOME is a large ecosystem (such as prairie, tropical rain forest, tundra) which has developed under prevailing climate and is sustained by it.

BIOSPHERE is a global ecosystem. In terms of thermodynamics, it is a closed system because it exchanges only energy (not matter) with its surroundings (open space).

BIOSPHERE RESERVES are protected areas of representative terrestrial and coastal environments which have been internationally recognized for their value in conservation and in providing research facilities. The Biosphere Reserves are sponsored by the UNESCO Man and the Biosphere program.

BIOTIC refers to living organisms.

CRITICAL ENVIRONMENTAL ZONE is an area of the world where long-term environmental sustainability is threatened or no longer possible.

ECOLOGY is the study of structure and function of ecosystems.

ECOSYSTEM The concept of ecosystem is used and defined in a number of different ways. The LTERM Panel provides four definitions that are in general agreement with the way the term is used in the report.

- is a basic functional unit of nature comprising both organisms and their non-living environment, intimately linked by a variety of biological, chemical and physical processes.
- is an ecological (i.e. interacting) system of plants, animals and microbes where the life activity of its individuals is supported by external supply and through-flow of energy and by selected elements which cycle. In terms of thermodynamics all ecosystems, except the entire Biosphere, are open systems, because they exchange energy and matter with their surroundings.
- is a community of organisms including humans, interacting with one another, plus the environment in which they live and with which they interact. Ecosystems are often embedded within other ecosystems of larger scale.
- is all the individuals, species and populations in a spatially defined area, the interactions among them and between the organisms and the abiotic environment.

ECOSYSTEM INTEGRITY is the self-organizing ability of an ecosystem to maintain itsidentity when environmental conditions change.

ECOTONE is an abrupt or diffused transition between distinct types of vegetation. The major Ecotones are between Biomes.

ECOZONE is an arbitrary unit of biogeographical/ecological classifications which follows agreed criteria; e.g. 15 non-marine ecological regions of Canada developed by Environment Canada for its State of the Environment Reporting.

ENERGY (high quality energy). The quality of energy is determined by the useful work which can be extracted from the energy, that is the available work in the energy. Formally the quality of energy is measured by its exergy. It is a measure of the potential of the energy to drive the system away from equilibrium. Irreversible processes destroy exergy. (Exergy is also called availability.) (see also: Ahern, J.E., 1980; Brzustowski, T.A., 1978; Edgerton, R.H., 1982; Moran, M.J., 1982)

ENVIRONMENT is all of the external abiotic and biotic conditions that affect a living system (an organism, community, ecosystem, etc.)

FRACTAL ANALYSIS is a mathematical way of describing objects that are not Euclidean; i.e. 1-, 2-, or 3-dimensional. It can be used to calculate the size of natural objects (e.g. the ocean's coastline).

GEOGRAPHIC INFORMATION SYSTEM (GIS) is a unit of computer hardware, software, and geographic data that capture, store, update, manipulate, analyze, and display geographically-referenced data.

GUILD is a group of species that exploit the same class of environmental resources in a similar way.

HABITAT is the location where an organism lives and is defined by its ecology.

INDICATOR SPECIES are typical, representative or sensitive organisms which respond to environmental conditions in a predictable manner.

INTEGRATED MONITORING is the repeated measurement of a range of related environmental variables and indicators in the living and non-living components of the environment for the purpose of studying large interconnected parts of an ecosystem or biosphere as a single system.

INTEGRITY: see ecosystem integrity.

KEYSTONE SPECIES are species that have an overriding influence on the structure andfunction of an ecosystem.

LANDSCAPE ECOLOGY is a study of spatial patterns and heterogeneity of communities and ecosystems, and spatial and temporal interactions across heterogeneous landscape.

METADATA are descriptions of archived data that permit an investigator in another discipline, at another place, and many years hence to work comfortably with the data sets.

POPULATION is a group of interbreeding organisms occupying a particular area.

RESOURCE INVENTORY is an identification of natural resources in a specific geographic area, and includes quantity, diversity, and quality. Resource inventories are conducted, for example, at yearly, 5-yearly, or 10-yearly intervals whereas monitoring is conducted much more frequently, sometimes continuously.

SPECIES RICHNESS is the number of species in a defined sampling area.

Appendix B
List of Key Canadian Monitoring Programs

This appendix presents a list of Canadian monitoring and research programs and proposed programs that the LTERM Panel felt relevant to this report. It is difficult to know what to include or exclude from such a list. The Panel may have been too inclusive with regard to some high-profile programs that are not truly of long-term duration. No doubt other relevant programs have been overlooked. However, the Panel is convinced that it has examined a representative number of programs, making it possible to reach the conclusions given in the text. Readers interested in further information on these programs may order a more detailed version of Appendix B from the CGCP Secretariat.

Program	Area / location
Acid Rain National Early Warning System	Forestry Canada
America's Interhemisphere Geo-Biosphere Organisation	North and South America
Arctic Monitoring and Assessment Programme	N.W.T. and the Yukon
Banff, Jasper and Waterton Lakes Water Quality Monitoring	Southwestern Alberta
Boreal Ecosystem-Atmosphere Study	Northern Saskatchewan
Breeding Bird Atlases	Canada except N.W.T., Newfoundland
Breeding Bird Survey	North America
Canadian Air and Precipitation Monitoring Network	Canada, mostly central and eastern
Canadian BIOCLIM	North America
Canadian Global Ecosystems Dynamics Programme	Oceans bordering Canada
Canadian Long Term Ecological Research Programme	Canada and adjacent areas
Central Canadian Rockies Ecosystem Model	Southwest Alberta and southeast B.C.
Christmas Bird Count	North and South America
Conservation Data Centres	North America
Continuous Plankton Recorder Programme	Scotian Shelf
Cryospheric System to Monitor Global Change in	Canada Sites throughout Canada
Elk Island Ecosystem Management Model	Central Alberta
Experimental Lakes Area	Near Kenora, Northwestern Ontario
Forest Bird Monitoring Programme	Ontario, New Brunswick, Saskatchewan
Forest Insect and Disease Survey	Productive forests throughout Canada
Fraser River Basin Prospects for Sustainability	Lower Fraser River, B.C.
Fraser River Salmon Migration and Production	Lower Fraser River & N. Pacific Ocean
Georgian Bay Islands National Park Herpetofaunal	Inventory Georgian Bay, Lake Huron, Ontario
Global Energy and Water Cycle Experiment	Boreal & tundra areas; Mackenzie Basin
Greater Fundy Ecosystem Research and Monitoring	Southern New Brunswick
Harkness Laboratory of Fisheries Research	Lake Opeongo, Algonquin Park, Ontario
Hawkeye Biochemical Site	Northwest Ontario
Integrated Research Catchments	North American boreal biome
International Tundra Experiment	Circumpolar and alpine sites
Kejimkujik National Park Ecological Science Centre	Southwestern Nova Scotia
Kluane Boreal Forest Ecosystem Project	Southwestern Yukon

Program	Area / location
La Mauricie National Park	Southern Québec
Mackenzie Basin Impact Study	N. Alberta and B.C., western N.W.T.
Migratory Monitoring	Long Point, southern Ontario
Model Forest Programme	Southern Canada
Monitoring Avian Productivity and Survivorship	North America
Nahanni National Park Reserve Water Quality Monitoring	Nahanni River, southwestern N.W.T.
National Ecological Monitoring and Research Network	Canada
Nest Record Scheme	All provinces and U.S.A.
North Columbia Mountains	Mt. Revelstoke/Glacier National Parks, B.C.
Northern Biosphere Observation and Modelling Experiment	Canada
Northwest Ontario Lake Size Series	Northwestern Ontario
Nova Scotia Shelf Groundfish Survey	Scotian Shelf
Ontario Rare Breeding Bird Programme	Saskatchewan and road-accessible Ontario
Paleolimnological & Limnological Studies of Arctic Lakes and Ponds	Circumpolar sites, mainly Canadian
Paleolimnological Inventories of Salinity, Climatic & Environmental Shifts	Manitoba to B.C. to the Yukon
Petawawa Research Forest	Eastern Ontario
Phytoplankton Monitoring Programme	Nova Scotia Atlantic coast
Point Pelee National Park Ecosystem Management	Programme Southern Ontario
Pukaskwa National Park Wolf Population Study	Northern Ontario
Quetico - Atikokan Environmental Research Initiative	Northwestern Ontario
Sasajewun Wildlife Research Station	Algonquin Park, Ontario
Scotia Fundy Biological Effects Monitoring	Nova Scotia south shore
Soil Quality Benchmark Sites	Southern Canada
Swan Lake Forest Research Reserve	Swan Lake, Algonquin Park, Ontario
Terramon	Newfoundland and Labrador
Terra Nova National Park Vegetation Mapping	Eastern Newfoundland
Truelove Lowland High Arctic Research Station	Devon Island, N.W.T.
Turkey Lakes Integrated Monitoring Site	Algoma, central Ontario

Appendix C
Acronyms

AMAP:	Arctic Monitoring and Assessment Program
BOREAS:	Boreal Ecosystem-Atmosphere Study
CGCP:	The Canadian Global Change Program of the Royal Society of Canada
EMAP:	Environmental Monitoring and Assessment Program
FAO:	Food and Agriculture Organization of the UN
GIS:	Geographic Information System
GCTE:	Global Change and Terrestrial Ecosystems (a Core Project of IGBP)
GESAMP:	Joint Group on Expert on the Scientific Aspects of Marine Environmental Protection
IAEA:	International Atomic Energy Agency
IAI:	Inter-American Institute for Global Change Research
ICSU:	International Council of Scientific Unions
IGBP:	International Geosphere-Biosphere Programme
IMO:	International Marine Organization
IOC:	Intergovernmental Oceanographic Commission
ITEX:	International Tundra Experiment
IUBS:	International Union of Biological Sciences
LOICZ:	Land-Ocean Interactions in the Coastal Zone
LTER:	Long-Term Ecological Research (A U.S. program)
LTERM:	Long-Term Ecological Research and Monitoring
MAB:	Man and the Biosphere
NBIOME:	Northern Biosphere Observation and Modelling Experiment
NOLSS:	Northwest Ontario Lake Size Series
SCOPE:	Scientific Committee on Problems of the Environment
SOER:	State of the Environment Reporting
UN:	United Nations
UNEP:	United Nations Environment Program
UNESCO:	United Nations Educational, Scientific and Cultural Organization
WMO:	World Meteorological Organization

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